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BASIC READINGS ON THE IDENTIFICATION OF HUMAN SKELETONS:

ESTIMATION OF AGE

Edited by

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FOREWORD

Physical anthropologists tend to generalize the anatomical information applied in skeletal identification. For instance, they speak of the first permanent molar as the "6 year molar" because in most white people this tooth erupts at approximately 6 years of age. They often forget, or seem unaware, that the first permanent molar may erupt any time within a two-year period between the ages of 5 and 7. In the same way they think of long bone epiphyses uniting and sutures closing at particular ages, ignoring the fact that variability is the rule in all such physiological events.

The original investigators were seeking generalizations and biological principles; but they qualified their conclusions by giving all of the evidence. However, the subsequent compilers of these data, the writers of anatomical textbooks and of identification guides, reiterated the generalizations and omitted the qualifications. It has been convenient, naturally, to use these compilations and thus misconceptions have been perpetuated.

When identification is confined to skeletons from archeological sources the use of such generalized knowledge is excusable; but when identification enters the medicolegal and military fields, the physical anthropologists involved must be aware of the full anatomical facts. In these two fields, the aim is to narrow down the various estimates to the closest defensible ranges. To state an unqualified age at death for a skeleton under such circumstances is an indication of inexperience or misinformation. And on the other hand, to fail to estimate the age of a skeleton within a narrow range, not so much because evidence of age is lacking, but because the secondary sources of information have merely outlined available data, likewise denotes inexperience or misinformation. Failure to comply with this medicolegal requirement can be the undoing of a physical anthropologist who undertakes to qualify in court as an expert.

Failure to use the primary sources in skeletal identification may be due to their unavailability. Although the reports have appeared in scattered places, few are old and out of print. In any case, it will be convenient to have them brought together in one place for ready reference. Such is the idea behind the present book.

The initial plan called for reprinting a selection of basic articles that would cover the whole field of skeletal identification. Almost immediately, however, efforts to assemble a table of contents revealed the impossibility of including, within a limit of 350 pages, much of the fundamental material. In any such selection, the omissions are bound to be glaring and hard to justify. Therefore, since age determination is perhaps the most vexing problem facing investigators of human skeletal remains, the editors adopted the suggestion of one of their consultants, Dr. T. D. McCown, and restricted the volume to this one important aspect of identification. The editors hope that this decision will be accepted as sound and will show the need for reprinting in equal fullness the basic articles on the remaining aspects—sex, race, stature, soft-part reconstructions, etc.

At this point the editors' concept of a basic contribution to the subject should be explained. In general, we mean a primary source which deals directly with the skeleton and which has not been superseded by a more critical study. In addition, we have in mind the population of the United States as providing the material for study, in as much as the book is likely to have its greatest distribution in this country, and reference to a specific local population is a primary desideratum in skeletal identification. All in all, we have not been able to hold entirely to this concept, and this is not surprising in view of the fact that there are so few direct observations on age changes in skeletons and some of these are unreliable. For example, some of Stevenson's observations on epiphyseal union have been shown to be incorrect with regard to sequence and hence ages (see p. 54). Yet Stevenson is still the only one who has reported direct detailed observations on this feature. Under the circumstances we have felt justified in republishing Stevenson's paper only by giving along with it Flecker's X-ray study of epiphyseal union in Australian Whites. By comparing these two papers a student can better understand the present status of our knowledge of epiphyseal union.

For the location of other comments on the merits of the selected papers, together with supplemental information, the table of contents should be consulted.

The editors would like to have included papers on the relationship of lengths of growing long bones to age, but they have not found anything that meets their requirements. Thus, there seems to be nothing for the postnatal period comparable even to Scammon's "Two simple nomographs for estimating the age . . . of the human fetus" (Anat. Rec., vol. 68, 1937, pp. 221-225). On the other hand, the editors have not included studies on changes in the internal structure of bone, since this requires damaging the specimens. In this connection, readers may wish to consult the recent paper by Gerhard Hansen: "Die Altersbestimmung am proximalen Humerus- und Femurende im Rahmen der Identifizierung menschlicher Skelettreste" (Wissensch. Ztschr. d. Humboldt-Univ. z. Berlin, Math.-Natur. Reihe Nr. 1, Jahrg. 3, 1953-54, pp. 1-73).

As already mentioned, the papers reprinted herewith have been abstracted or otherwise used in guides on identification procedures. Among these guides, the following may be recommended on account of the inclusion by the authors of original data of their own:

Boyd, J. D. and J. C. Trevor—Race, sex, age and stature from skeletal material. Chap. 7, pt. 1 in "Modern Trends in Forensic Medicine" (Ed. by Keith Simpson). Butterworth & Co., Ltd., London, 1953.

Gustafson, Gösta and Keith Simpson—Dental data in crime investigation. Ibid. Chap. 7, pt. 2.

Krogman, W. M.—A guide to the identification of human skeletal material. FBI Law Enforcement Bull., vol. 8, no. 8, 1939.

Krogman, W. M.—The human skeleton in legal medicine. Chap. (pp. 1-92) in "Symposium on Medicolegal Problems" (Ed. by S. A. Levinson). J. B. Lippincott Co., Phila., 1949.

Scott, David B.—Dental evidence in identification and criminology. Chap. 18 in "Legal Medicine" (Ed. by R. B. H. Gradwohl). C. V. Mosby Co., St. Louis, 1954.

Stewart, T. D.—Evaluation of evidence from the skeleton. Ibid., chap. 17.

The editors are indebted to the several authors, editors and publishers for permission to reprint. We take this opportunity to express our appreciation for council and encouragement given by W. M. Krogman, T. D. McCown, and S. L. Washburn. We also appreciate the complete freedom given us by the Wenner-Gren Foundation for Anthropological Research in allowing us to shape the contents of this book after they had agreed to publish it.

T. D. Stewart

Mildred Trotter

July 15, 1954 Editors

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CRITICAL COMMENTS ON DEVELOPMENT AND ERUPTION OF TEETH

The fact that two of the three articles reprinted here deal with tooth eruption places major emphasis upon this process, as is perhaps proper, since in the gross examination of skeletal remains the visible teeth furnish ready evidence of age. On the other hand, the age as assessed from eruption often can be refined by examining the unerupted enamel crowns and the buried roots to see their stages of development. Sometimes sufficient details of this nature can be discovered without the use of X-rays, as for instance by extracting the incisors, or other teeth with straight roots, which may be loose. The article by R. Kronfeld gives dates for the stages of crown and root growth.

It is noteworthy that most tables and illustrations relating to the development and calcification of the human teeth are based on Kronfeld's work. Whatever modifications others have introduced have been left unexplained. Among still unpublished studies on this subject may be mentioned that by Carmen M. Nolla based on serial annual radiographs of 25 boys and 25 girls at the University of Michigan Elementary School. An abstract of this work appeared in the Journal of Dental Research in 1953 (vol. 32, no. 5, p. 673). It should be obvious from the work of Kronfeld and Nolla that, unlike the stages of tooth eruption, the stages of tooth development and calcification are based on inadequate series. Probably, therefore, the variability of these processes is not sufficiently expressed.

Recently the teeth have furnished another clue to age through studies of enamel surfaces under high magnification. Because specialized equipment is required, it is sufficient here to refer the reader to the literature: "Replica studies of changes in tooth surfaces with age" by David B. Scott, Harry Kaplan and Ralph W. G. Wycoff (J. Dent. Res., vol. 28, no. 1, Feb., 1949, pp. 31-47).

Reprinted from The Bur, Vol. 35, No. 1, March, 1935, pp. 18-25.

DEVELOPMENT AND CALCIFICATION OF THE HUMAN DECIDUOUS AND PERMANENT DENTITION

*(Summary of the Histologic and Roentgenographic Findings of Dr. W. H. G. Logan and Dr. R. Kronfeld.)**

RUDOLF KRONFELD, M. D., D. D. S.

IN 1929 Dr. W. H. G. Logan began an investigation of the minute anatomy of the infant's upper jaw for the purpose of obtaining more accurate and detailed data for surgical procedures in early infancy (cleft palate operation).

Soon after the first histologic sections had been made through the maxillae from children of a few months of age, it became apparent that most of the information contained in the standard textbooks of dental anatomy and histology was inadequate and inconsistent. Some authors followed the table compiled by Legros and Magitot in 1873, others the diagrams of Black (1883) and of Peirce (1884); beyond this there was little additional knowledge on the subject to be found in literature. These tables differ widely on some fundamental data: for example, Legros and Magitot give the time for the onset of calcification of the second bicuspids as one month after birth, Peirce as the fifth year.

Under these circumstances it appeared advisable and necessary to extend this histologic and roentgenographic study. Dr. Logan was originally interested only in the position and development of the maxillary teeth during the first six months after birth. Later additional specimens of human jaws were procured, and the writer became associated with the investigation in order to work out systematically the development and calcification of all deciduous and permanent teeth from birth to adolescence. Up to the present, histologic serial sections have been prepared through more than thirty human jaws, ranging in age from birth to fifteen years.

These sections demonstrated the exact position, state of development, and degree of calcification for each tooth at different ages. The data for the onset and sequence of calcification as found in these preparations were corroborated by the clinical observations

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*Read before the Sixty-ninth Annual Session of the Ohio State Dental Society, Columbus, Ohio, November 20, 1934.

From the Research Department of the Chicago College of Dental Surgery, Dental Department of Loyola University.

of the relative distribution of hypoplastic defects in the enamel; they were also fully substantiated by recent roentgenographic studies (Bustin and Priesel; Hess, Roman, and Lewis; Broadbent), with the only reservation that the roentgenologist finds the first appearance of calcification from two to six months later than it can be found in histologic sections.

Space does not permit a more detailed discussion of the technique of our investigation, nor of all the findings obtained. Several articles have already been written on this subject, all of which were based on this material.* At this time only the principal data for onset of calcification, completion of crown and root, and eruption will be given; first, these data will be given for each tooth separately, and then they will be arranged in a table for the entire dentition.

DECIDUOUS DENTITION

I. Upper and lower central incisors:
   Calcification begins: 5 months in utero
   Crown completed: 4 months
   Eruption: 6-8 months
   Root completed: 1½-2 years
   Root resorption begins: 5-6 years
   Shedding: 6-7 years

II. Upper and lower lateral incisors:
   Calcification begins: 5 months in utero
   Crown completed: 5 months
   Eruption: 8-10 months
   Root completed: 1½-2 years
   Root resorption begins: 5-6 years
   Shedding: 7-8 years

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*Logan, W. H. G. "Direct Versus Indirect Application of Force for the Surgical Correction of Complete Congenital Cleft of Palate." *J. A. D. A.* 17:827, 1930.

Logan, W. H. G. "Surgical Correction of Complete Congenital Cleft of Palate." Eighth International Dental Congress, Paris, August, 1931.

Kronfeld, Rudolf. "Resorption of the Roots of Deciduous Teeth." *D. Cosmos* 74:103, 1932.

Logan, W. H. G. and Kronfeld, Rudolf. "Development of the Human Jaws and Surrounding Structures from Birth to the Age of Fifteen Years." *J. A. D. A.* 20:379, 1933.

Logan, W. H. G. "A Histologic Study of the Anatomic Structures Forming the Oral Cavity." *J. A. D. A.* 22:3, 1935.

Kronfeld, Rudolf. "The First Permanent Molar. Its Condition at Birth and Its Postnatal Development." To appear in the *J. A. D. A.*

Kronfeld, Rudolf. "Postnatal Development and Calcification of Human Upper and Lower Anterior Permanent Teeth." To appear in the *J. A. D. A.*

III. Upper and lower cuspids:
Calcification begins: 6 months in utero
Crown completed: 9 months
Eruption: 16-20 months
Root completed: 2½-3 years
Root resorption begins: 6-7 years
Shedding: 10-12 years

IV. Upper and lower first molars:
Calcification begins: 5 months in utero
Crown completed: 6 months
Eruption: 12-16 months
Root completed: 2-2½ years
Root resorption begins: 4-5 years
Shedding: 9-11 years

V. Upper and lower second molars:
Calcification begins: 6 months in utero
Crown completed: 10-12 months
Eruption: 20-30 months
Root completed: 3 years
Root resorption begins: 4-5 years
Shedding: 10-12 years

PERMANENT DENTITION

I. Central incisors:

1. Upper—
Calcification begins: 3-4 months
Crown completed: 4-5 years
Eruption: 7-8 years
Root completed: 10 years

2. Lower—
Calcification begins: 3-4 months
Crown completed: 4-5 years
Eruption: 6-7 years
Root completed: 9 years

II. Lateral incisors:

1. Upper—
Calcification begins: 1 year
Crown completed: 4-5 years
Eruption: 8-9 years
Root completed: 11 years

2. Lower—
Calcification begins: 3-4 months
Crown completed: 4-5 years

Eruption: 7-8 years
Root completed: 10 years

III. Cuspids:

1. Upper—
   Calcification begins: 4-5 months
   Crown completed: 6-7 years
   Eruption: 11-12 years
   Root completed: 13-15 years

2. Lower—
   Calcification begins: 4-5 months
   Crown completed: 6-7 years
   Eruption: 10-11 years
   Root completed: 12-14 years

IV. First bicuspids:

1. Upper—
   Calcification begins: 1½-1¾ years
   Crown completed: 5-6 years
   Eruption: 10-11 years
   Root completed: 12-13 years

2. Lower—
   Calcification begins: 1¾-2 years
   Crown completed: 5-6 years
   Eruption: 10-12 years
   Root completed: 12-13 years

V. Second bicuspids:

1. Upper—
   Calcification begins: 2-2¼ years
   Crown completed: 6-7 years
   Eruption: 10-12 years
   Root completed: 12-14 years

2. Lower—
   Calcification begins: 2¼-2½ years
   Crown completed: 6-7 years
   Eruption: 11-12 years
   Root completed: 13-14 years

VI. Upper and lower first molars:
Calcification begins: at birth
Crown completed: 2½-3 years
Eruption: 6-7 years
Root completed: 9-10 years

VII. Second molars:

1. Upper—
   Calcification begins: 2½-3 years
   Crown completed: 7-8 years
   Eruption: 12-14 years
   Root completed: 14-16 years

2. Lower—
   Calcification begins: 2½-3 years
   Crown completed: 7-8 years
   Eruption: 12-13 years
   Root completed: 14-15 years

VIII. Third molars:

1. Upper—
   Calcification begins: 7-9 years
   Crown completed: 12-16 years
   Eruption: 17-30 years
   Root completed: 18-25 years

2. Lower—
   Calcification begins: 8-10 years
   Crown completed: 12-16 years
   Eruption: 17-30 years
   Root completed: 18-25 years

If this material is arranged in the form of a table, it appears as on page 8.

It will be noted that some of the data contained in this table vary slightly from those given in the *Journal of the American Dental Association,* 1933, Vol. 20, page 420. This is due to the fact that during the last two years a considerable amount of additional human material was sectioned and studied, with the aid of which it was possible to work out the data for the onset of calcification of the permanent dentition more specifically than was possible in 1932.

I shall try to summarize the most important facts concerning the development of the permanent dentition with special consideration of those points which heretofore were either unknown or usually stated incorrectly:

Incisors

The upper and lower permanent central incisors begin to calcify during the first six months of life.

The lower permanent lateral incisor begins to calcify simultane-

CHRONOLOGY OF THE HUMAN DENTITION

LOGAN and KRONFELD (slightly modified by McCALL and SCHOUR)

Tooth			Hard Tissue Formation Begins	Amount of Enamel Formed at Birth	Enamel Completed	Eruption	Root Completed
Deciduous dentition	Maxillary	Central incisor	4 mos. in utero	Five-sixths	1½ mos.	7½ mos.	1½ yrs.
		Lateral incisor	4½ mos. in utero	Two-thirds	2½ mos.	9 mos.	2 yrs.
		Cuspid	5 mos. in utero	One-third	9 mos.	18 mos.	3¼ yrs.
		First molar	5 mos. in utero	Cusps united	6 mos.	14 mos.	2½ yrs.
		Second molar	6 mos. in utero	Cusp tips still isolated	11 mos.	24 mos.	3 yrs.
	Mandibular	Central incisor	4½ mos. in utero	Three-fifths	2½ mos.	6 mos.	1½ yrs.
		Lateral incisor	4½ mos. in utero	Three-fifths	3 mos.	7 mos.	1½ yrs.
		Cuspid	5 mos. in utero	One-third	9 mos.	16 mos.	3¼ yrs.
		First molar	5 mos. in utero	Cusps united	5½ mos.	12 mos.	2¼ yrs.
		Second molar	6 mos. in utero	Cusp tips still isolated	10 mos.	20 mos.	3 yrs.
Permanent dentition	Maxillary	Central incisor	3 - 4 mos.	....	4 - 5 yrs.	7- 8 yrs.	10 yrs.
		Lateral incisor	10 -12 mos.	....	4 - 5 yrs.	8- 9 yrs.	11 yrs.
		Cuspid	4 - 5 mos.	....	6 - 7 yrs.	11-12 yrs.	13-15 yrs.
		First bicuspid	1½- 1¾ yrs.	....	5 - 6 yrs.	10-11 yrs.	12-13 yrs.
		Second bicuspid	2 - 2¼ yrs.	....	6 - 7 yrs.	10-12 yrs.	12-14 yrs.
		First molar	at birth	Sometimes a trace	2½- 3 yrs.	6- 7 yrs.	9-10 yrs.
		Second molar	2½- 3 yrs.	....	7 - 8 yrs.	12-13 yrs.	14-16 yrs.
		Third molar	7 - 9 yrs.	....	12 -16 yrs.	17-21 yrs.	18-25 yrs.
	Mandibular	Central incisor	3 - 4 mos.	....	4 - 5 yrs.	6- 7 yrs.	9 yrs.
		Lateral incisor	3 - 4 mos.	....	4 - 5 yrs.	7- 8 yrs.	10 yrs.
		Cuspid	4 - 5 mos.	....	6 - 7 yrs.	9-10 yrs.	12-14 yrs.
		First bicuspid	1¾- 2 yrs.	....	5 - 6 yrs.	10-12 yrs.	12-13 yrs.
		Second bicuspid	2¼- 2½ yrs.	....	6 - 7 yrs.	11-12 yrs.	13-14 yrs.
		First molar	at birth	Sometimes a trace	2½- 3 yrs.	6- 7 yrs.	9-10 yrs.
		Second molar	2½- 3 yrs.	....	7 - 8 yrs.	11-13 yrs.	14-15 yrs.
		Third molar	8 -10 yrs.	....	12 -16 yrs.	17-21 yrs.	18-25 yrs.

ously with the upper and lower central incisors; the upper permanent lateral incisors do not show evidence of calcification until the age of one year. This explains why this tooth may escape hypoplasia of its enamel in patients in whom the incisal portions of the upper and lower central incisors, lower lateral incisors and cuspids, and the occlusal portion of the first permanent molars are hypoplastic.

Cuspids

The cuspids begin to calcify during the first six months of life, and not, as erroneously stated in most dental literature, during the third year. Hence they are frequently hypoplastic together with the central incisors and the lower lateral incisors.

Bicuspids

The bicuspids begin to calcify between the ages of one and one-half and two and one-half years; the upper bicuspids are somewhat ahead of the lower ones, and the first bicuspids are ahead of the second bicuspids.

At birth and during the first year of life the germs of the bicuspids lie on the occlusal side of the crowns of their deciduous predecessors. During the second year they are found on the lingual side of the deciduous molars, and from the third year on to the time of eruption the bicuspids are located between and above (maxila) or below (mandible) the roots of the deciduous molars.

First Molars

The first permanent molar begins to calcify at birth or shortly thereafter. Occasionally in the new-born, calcification has begun in the buccomesial cusp. During the first three months of postnatal life calcification begins in all cusps. At about six months the cusps begin to fuse, and at the age of three years the crown is completed. The much quoted age, "25th fetal week," for the onset of calcification of the first permanent molar has not been corroborated by any finding in our own material nor by any other histologic or roentgenographic investigation.

Second Molars

The calcification of the second permanent molars begins toward the end of the third year.

Third Molars

The calcification of the third molar may begin any time after the

seventh year. The upper third molars usually precede the lower ones.

The calcification of the permanent dentition is entirely a postnatal process; at birth no calcification is found in any of the permanent teeth except for an occasional very small amount in the first permanent molars.

At the age of one year calcification is well under way in the first permanent molars and in the six anterior teeth, with the exception of the upper lateral incisors.

At the age of three years calcification has begun in all of the permanent teeth except the third molars; the crown of the first permanent molars is completed.

Between four and five years the crowns of the incisors are fully formed; between five and seven years the crowns of all the remaining permanent teeth, with the exception of the third molars, are completed.

Reprinted from the Journal of Dental Research, Vol. 25, No. 1, February, 1946, pp. 43-66.

ORDER AND AGE OF ERUPTION FOR THE DECIDUOUS DENTITION[1]

HOWARD V. MEREDITH

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Presently available research literature includes no less than a score of North American studies pertaining to the time and sequence of eruption of the primary or "milk" teeth. For only about one-sixth of these studies is the medium of original report a dental periodical, the remaining five-sixths are in anthropological, biological, child development, medical (mainly pediatric) and psychological publications. It is a major objective of this paper to bring together these widely scattered reports and make their contents more readily accessible to members of the dental profession.

A second major objective of the paper is that of presenting an epitome of research knowledge concerning the age and order of eruption of deciduous teeth in North American children. This, of course, presupposes a systematic and comprehensive integration of the materials from different studies.

The two objectives determine the two parts of the paper: The first—colligation—is carried out under the caption "Presentation of Research Materials" and the second—synthesis—under the caption "Generalizations." There are incorporated in both parts the findings from two previously unpublished investigations.

PRESENTATION OF RESEARCH MATERIALS

As a point of departure, reference may be made to a "Course of lectures on dentition and its derangements" published by Jacobi (9) in 1860. The materials in these lectures pertaining to eruption of the deciduous teeth were drawn entirely from European studies.

Minot (13), in 1873, wrote a paper "On the primary dentition of children" which included statements relating to the order and age of eruption based upon his "own experience." On eruption of the first tooth, Minot stated: "Judging from my own observation, I should put six and a half months as the average date of the appearance of the first tooth" (13, p. 9). The usual sequence of eruption for the full complement of deciduous teeth was given as follows: The "two lower central incisors" at $6\frac{1}{2}$ to 7 months; "The four upper incisors, of which the two central ones are the first to appear," at 9 to $10\frac{1}{2}$ months; the "upper anterior molars," lower lateral incisors, and "lower anterior molars"—in this order—at $12\frac{1}{2}$ to 14 months; "the four canines" at 18 to 21 months; and "the four posterior molars" at 26 to 30 months.

[1] Received for publication January 14, 1946.

At the 1876 annual meeting of the American Dental Association, McQuillen "made a verbal report on the order of eruption of the deciduous teeth" (11, p. 483). After commenting that instances were on record of infants "having been born with teeth," he stated: "The central incisors usually erupt from the sixth to the eighth month, and the laterals from the seventh to the ninth month; the first molars from the fourteenth to the sixteenth month; the second molars between the twenty-fourth and thirtieth months" (11, p. 484). No mention was made of the typical age of eruption of the deciduous canines, nor was there any reference to the source of the information on other teeth. McQuillen's report was discussed by a "Dr. Shepard," who presented "a case of variation in the time of eruption of the deciduous teeth in the same family; one boy had erupted a tooth at four months of age, and at eight months had eight teeth, while another had no teeth till eight months old, and at one year had but five teeth" (11, p. 527).

Shinn (20), in 1893, published "notes" on the eruption of the "milk" teeth in a single female infant. The subject was a physically normal infant born and reared "on a fruit ranch near Niles, in the neighborhood of San Francisco Bay" (20, p. 5). She was of 'Old American' stock, "all four grandparents being descended from early colonists" (20, p.5). Shinn observed: ". . . two teeth were cut just after the close of the fifth month. In the ninth and tenth months six more teeth were cut. . . the first molar came through early in the fifteenth month" and "teething was distributed quite equally" throughout the ensuing months "to the end of the nineteenth" (20, p. 8). "In the latter part of the twenty-seventh month, two more molars were cut" (20, p. 89). It may be inferred that at 1 year of age the 8 erupted teeth were incisors, by 2 years of age the first molars and canines had erupted, and the teeth erupting in the third year were second molars.

In 1895, a paragraph describing original data for eruption of the first tooth in New York City infants was printed in *The Dental Review* and reproduced in *Ash's Quarterly Circular* (1). To quote: "With the aid of Dr. Purdy, Dr. J. Lewis Smith has kept records of the average time of appearance of the teeth in children at the out-door department of Bellevue Hospital, excluding cases of rickets, which were most common in Italians and next in Negroes. In 200 infants without signs of rickets, the first tooth had appeared as follows: In 3 infants at two months, in 20 at five months, in 24 at six months, in 37 at seven months, in 28 at eight months, in 20 at nine months, in 14 at ten months, in 15 at eleven months, in 8 at twelve months, and in 1 at thirteen months of age" (1, p. 203). Statistical reduction of these data yields the following tabulation:

Age at Eruption of First Tooth (mos.) in New York City Infants

MINIMUM	PERCENTILES			MAXIMUM
	25	50	75	
2	5.8	7.1	8.8	13

The mean age at eruption was 7.3 months, the median age (as above) 7.1 months.

Hrdlicka (8), in 1908, reported observations for deciduous eruption obtained

on American Indian children of the Pima and Apache tribes of Arizona. For "full-bloods" of "known age," there were 120 subjects distributed from birth to 6 years—between the ages of 2 months and 2½ years the numbers were 35 Pima (14 males, 21 females) and 35 San Carlos Apache (17 males, 18 females). The data were collected from single examinations made between 1898 and 1905. Hrdlicka noted that it was customary practice among these tribes for infants to be at least partly breast fed until after 2 years of age. Other statements pertaining to diet were: "For the first five or six months the Apache baby gets only mother's milk; later on it receives a little food of any kind eaten by the mother" (8, p. 76); the Pima infant, "in addition to being nursed," is sometimes fed "on fruit and other things from the time it is about four or five months old" (8, p. 78).

"Among the San Carlos Apache the youngest child with one or more teeth was a girl in whom both lower middle incisors appeared at 2½ months, and among the Pima a girl who had both lower median incisors fairly developed at 4 months and 13 days. Among the Apache the oldest infant without teeth was a girl of 7 months, and among the Pima a boy of 7 months and 20 days.

"The upper median incisors follow the lower. . . .among the Apache the youngest child in which both these teeth were erupted was.7 months and 20 days, among the Pima 7 months and 17 days, but in both children the teeth had been out for some days . . . the oldest subjects in whom the eruption of the upper median incisors had not taken place were a 12½ months Apache girl and a Pima girl of the same age.

". . . the upper lateral incisors. . . had just broken through in an Apache girl of 7 months and 20 days and in a Pima boy of 7 months and 17 days. . . the oldest children in whom both were still lacking were an Apache gril of 14 months and a Pima girl of 1 year and 16 days old.

"The lower lateral incisors. . . were seen earliest in an Apache girl of 8½ months and in a Pima girl of 9 months. The oldest Apache girl in whom both were lacking was 12½ months; the oldest Pima child 18 months and 2 days old. In three instances one or both of these teeth were out before the upper lateral incisors.

"Among the Apache children in two cases all the anterior premolars were out before the appearance of any of the canines, and there are indications of similar precedence among the Pima. . . .As to the time of appearance, in the Apache the anterior premolars were not present in any child up to 14 months, but were found in all of 16¾ months and older, while in the Pima the teeth were not erupted in any subject up to 15½ months, and were present in all but one of the children of 17½ months and older.

"The canines were seen first in an Apache girl of 19 months 10 days, all being present in every older child, and in a Pima girl of 17½ months, being present in all but two older subjects (of 18 months and 18 months and 2 days respectively).

"The posterior premolars. . . were all present in an Apache child of 19 months 10 days, and in another of 20 months; these had not all erupted in three Indian children of from 22 to 23 months of age and were wholly lacking in one of 25 months, but were present in every case from 26 months upward. Among the Pima none of these teeth were found in children 2 years or younger; the two lower were present in a boy of 25 months, and were just appearing in another of 26 months 9 days, but were present in every subject above this age" (8, pp. 96–97).

It was recognized by Hrdlicka that for each tribe and sex the number of children studied was "very limited."

In 1913, Herrman (7) published eruption data for the "first teeth" collected on infants born "June 1, 1909, to June 1, 1910" at Lebanon Hospital, New York. The subjects were approximately 50% of Russian-born parentage, 30% of north-

west European ancestry, and 20% of southeast European descent. Their mothers took them to the Hospital Dispensary at frequent intervals over the first 2 years of postnatal life; here, the infants were examined and the mothers given advice on dietary and health care. The sample seemingly included "careless" as well as conscientious mothers, and fairly sick as well as healthy infants. Over four-fifths of the subjects "received breast milk exclusively or partly for at least five months" (7, p. 110).

Eruption Age for "First Teeth" (mos.) in White Infants Studied 1909–11

N	MEAN	S.D.	MINIMUM	PERCENTILES		MAXIMUM
				25	75	
121	8.2	1.8	4.4	7.0	9.2	12.5

Discussion of findings was restricted to a single notation: "Seventy per cent had their first teeth at or before eight and a half months" (7, p. 109).

Two series of data representing eruption of the deciduous teeth in children living in an institution—"The Home for Hebrew Infants, New York City"—were analyzed in 1927 by Boas (2). For one series, the procedure was as follows: Children were "observed at intervals of three months by Dr. Louis N. Sullivan and Mr. Maynard. . . .The teeth were recorded as absent, erupting or fully erupted. . . .The age at the time of eruption was assumed as the middle date between the last date of absence of a tooth and the first date of its full presence. In cases of erupting tooth, twenty days were added to the date of the observation when eruption was recorded" (2, p. 245). The analysis for these materials is presented in the upper portion of Table I.

The second series of data was characterized as "observations of presence or absence" for deciduous teeth "at given ages." In this series, it was possible to include "a much larger number" of subjects (*e.g.*, "children who were just about to be discharged from the Infant Home"): Specifically, the average number examined at each month of age was 20 for males and 13 for females. There was separate treatment of the data on each sex. The lower portion of Table I reproduces findings from reduction of these materials.

The central tendency values (medians and means) from Table I were discussed with reference to order of eruption of teeth, the means with reference to sex-differences in age of eruption, and the standard deviations with reference to their magnitude for different teeth. To quote: "The variability is least for the inner incisor, and reaches its maximum for the second deciduous molar" (2, p. 253); ". . . it would seem that there is no characteristic sex difference in the time of eruption for these children" (2, p. 253); ". . . for the inner incisor there is the well known characteristic difference in favor of the lower jaw. . . . There is also a slight difference in favor of the lower jaw in the case of the second deciduous molar. . . . It seems likely that the outer incisor of the upper jaw precedes slightly in eruption the corresponding tooth of the lower jaw" (2, p. 253). Boas further stated: ". . . it seems that the Home children are very much retarded in the eruption of deciduous teeth . . . possibly this is due to the poor condition in which most of the children are when taken to the Home" (2, p. 252).

Sawtell (19), in 1929, reported findings for eruption of the deciduous dentition

on two socio-ethnic groups. One group consisted of "twenty-eight Sicilian infants from the lower East Side of New York"—"fourteen boys, average age 9.1 months, fourteen girls, 8.1 months" (19, pp. 62, 73). Eruption data on these subjects were made available by Mr. John C. Gebhardt. Sawtell found that the mean number of "incisors present" approximated 2.6 for the males and 1.4 for the females.[2] Comprising the second group were 16 males and 14 females between the ages of 30 and 42 months in attendance 1925–27 at the nursery school

TABLE I

Eruption of Deciduous Teeth (mos.) in "Hebrew Infants"

Age of eruption for both sexes combined

	N	MINIMUM	PERCENTILES			MAXIMUM
			25	50	75	
Lower first incisor*	45	4.5	9.3	11.1	13.4	19.5
Upper first incisor	53	4.5	10.8	13.1	14.8	23.5
Upper second incisor	68	8.5	13.3	16.3	18.7	28.5
Lower second incisor	54	8.5	14.1	16.8	18.4	30.5
Lower first molar	70	13.5	18.0	19.9	21.1	29.5
Upper first molar	80	13.5	18.0	20.2	22.0	28.5
Lower canine	89	13.5	19.6	21.8	24.8	34.5
Upper canine	97	13.5	19.2	21.8	24.9	33.5
Lower second molar	80	14.5	24.9	27.4	30.1	40.5
Upper second molar	82	14.5	25.3	28.6	31.1	44.5

Age of eruption for each sex separately

	LOWER TEETH				UPPER TEETH			
	Males		Females		Males		Females	
	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
First incisor	11.0	2.8	11.0	3.0	12.8	2.8	13.5	3.1
Second incisor	16.8	4.0	16.4	4.3	15.4	3.4	15.0	3.5
First molar	19.5	3.1	19.6	4.4	19.2	2.9	19.4	4.2
Canine	21.7	4.5	21.6	4.9	21.1	4.5	21.8	5.1
Second molar	28.4	4.8	28.1	4.9	28.7	5.1	28.5	4.8

* It was not specified whether the data symbolized (a) age of eruption of each tooth on one side of the mouth, (b) average age of eruption for each pair of corresponding teeth on the right and left sides, or (c) age of eruption of the first of each pair of corresponding teeth without reference to the side of the mouth on which this appeared.

of the Bureau of Educational Experiments, New York City. These subjects were predominantly of northwest European ancestry and from homes of "moderate prosperity" in the "Chelsea or Greenwich Village sections of New York" (19, p. 62). Four of the 30 (13%) showed incomplete eruption of the deciduous dentition: At 34 months of age, a boy lacked "the upper second molars" and a girl "the upper right second molar"; at 37 months, a girl lacked both upper second

[2] The reader is cautioned not to overlook the fact that the Sicilian females averaged one month younger than the Sicilian males.

molars, and a boy, "known to have an early rachitic history, . . . had only sixteen teeth" (19, p. 83).

Using the results of annual dental examinations made over a 4-year period, Pyle and Drain analyzed data for eruption of the deciduous teeth on 165 males and 175 females "in attendance at the preschool laboratories of the Iowa Child Welfare Research Station" (15, p. 152). The subjects were largely of northwest European lineage and came from "homes where information and resources for proper health and dental instruction were easily available" (15, p. 147). Group findings are reproduced in Table II.

TABLE II

Mean Number of Deciduous Teeth Erupted at Successive Ages

Data accumulated 1927–31 on Iowa City private school children

AGE GROUP		MALES		FEMALES	
Midpoint	Range	N	Mean	N	Mean
mos.	*mos.*				
24	18 thru 29	22	17.4	19	16.2
36	30 thru 41	34	19.6	49	19.6
48	42 thru 53	49	20.0	50	20.0
60	54 thru 65	60	20.0	57	20.0

"The youngest boy with a full complement was 27 months . . . the youngest girl 29 months. . . . The oldest boy who had less than twenty teeth was 35 months old and the oldest girl 37 months" (15, p. 148).

Findings for age of eruption of the first tooth, and for status of the deciduous dentition at the beginning of the third year, were published in 1931 by Wallis (22). The data on the first tooth were secured through the City and Country School, New York City: "From the registrar's information blank is the mother's

TABLE III

Eruption of Deciduous Teeth in New York "Private School" Children

Age (mos.) at which "mothers said positively" first tooth appeared

SEX	N	MEAN	S.D.	MINIMUM	MAXIMUM
Males	147	7.6	2.3	3	15
Females	130	7.6	2.4	3	16

Status of deciduous dentition in age period 22 to 27 months

SEX	N	PERCENTAGE WITH:		MEAN NUMBER OF TEETH	S.D.
		16 teeth	20 teeth		
Males	16	56	25	17.1	1.8
Females	15	40	33	16.7	3.0

statement, verified whenever possible by the baby book, of the date on which the first tooth erupted" (22, p. 129). At ages "twenty-two to twenty-seven months," 31 children were examined over the period 1926–29 at the nursery school of the Bureau of Educational Experiments, New York City. Socio-economically, these subjects were of "the favored class"; ethnically, they typified third-generation United States children of north European stocks. Table III displays the results from both analyses. Wallis recognized that the sources of unreliability were greater for the first tooth data than for the data from examination of children in the nursery school.

Eruption ages for all 20 deciduous teeth were reported by Dafoe and Dafoe (3) on each of the Dionne quintuplets. The subjects were described as female monozygotic siblings, prematurely born by approximately 2 months, of French-Canadian descent, and reared under well controlled provisions for health protection and supervision. Their dietary included breast milk until 4.5 months, tomato and orange juice from 5 weeks, cod liver oil from 8 weeks, ferrous chloride and prune juice from 4 months, cereal and evaporated milk from 5 months, egg yolk, cooked vegetables and fruit pulp from 8 months, and calves liver from 1 year. Each had a "moderately severe infection" for 1 week in the fourth month—cough, nasal discharge, fever, diarrhea, cramp and distention; mild to moderate respiratory infections occurred in the eleventh and fourteenth months; shortly before eighteen months, and again in the twenty-first and twenty-second months, each had coryza in conjunction with vomiting and loose stools. All received "three diphtheria toxoid injections at three-week intervals when $1\frac{1}{2}$ years of age" (3, p. 422). See Table IV for an itemization of the ages of eruption in each individual. Dafoe and Dafoe drew the following comparative conclusion: "The eruption times of the deciduous dentition in the quintuplets have been definitely slower than normal" (3, p. 419).

Poole, Hamil, Cooley and Macy, in 1937, studied the association between age of eruption of the deciduous teeth and "early addition of the antineuritic factor, vitamin B_1, . . . to an ordinary milk formula" (14, p. 730). The subjects were 117 full-term, non-twin, well infants "living in their own homes and cared for by their own parents" (14, p. 731). Roughly two-thirds were White and one-third Negro. They were drawn from "the indigent and near-indigent class of the cosmopolitan population of Detroit" and were studied 1934–35 through the Research Laboratory of the Children's Fund of Michigan and the Children's Hospital of Michigan. When initially examined they "ranged from 1 to 10 weeks of age, with an average of 5.5 weeks" (14, p. 748): From the time of this examination all were artificially fed. Their mothers were instructed at a clinic and by visiting nurses regarding feeding management and health care. The basic milk formula given all infants consisted of "evaporated milk, water and corn syrup acidified by the addition of commercially dehydrated lemon juice powder" (14, p. 749); cereal was added to the dietary at 4 to 5 months, strained carrots and peas at 5 to 6 months, prune pulp and apple sauce at 6 to 7 months, and eggs at 11 months; cod liver oil was given to yield 250–600 U.S.P. units of vitamin D daily. "At the first visit to the clinic, the babies were assigned . . . alternately to 2

groups"; one group received "formula containing evaporated milk to which at the time of manufacture had been added vitamin B (B_1) in the form of a water-soluble extract of rice polishings," while the other group was given a formula which "contained no vitamin B extract"; "the average estimated vitamin B_1

TABLE IV

Eruption Age of Deciduous Teeth (mos.) in 5 Prematurely Born, Monozygotic Females Studied 1934–37

	RIGHT SIDE					LEFT SIDE				
	A	C	E	M	Y*	A	C	E	M	Y
Lower teeth										
First incisor	11	12	15	15	15	14	11	15	13	14
Second incisor	16	15	16	16	16	16	14	17	15	17
First molar	20	19	18	18	19	18	19	20	18	30
Canine	23	23	24	23	24	23	23	25	23	22
Second molar	38	36	37	35	39	37	37	34	36	?†
Upper teeth										
First incisor	12	13	14	13	12	13	13	14	14	12
Second incisor	15	14	16	16	16	16	15	18	15	17
First molar	19	19	19	19	20	20	21	21	20	20
Canine	26	25	27	26	26	25	26	27	24	24
Second molar	37	35	38	36	38	36	36	36	37	38

* The initials of the children's names in alphabetical order: Annette, Cecile, Emelie, Marie, Yvonne.

† "Eruption not completed" at "40 months" (3, p. 420).

TABLE V

Mean Number of Deciduous Teeth Erupted at Selected Ages

Data accumulated 1934–35 on White and Negro infants of the lower classes fed special diets

AGE GROUP		CONTROL DIET		ADDITIONAL B_1 DIET	
Midpoint	Range	N	Mean	N	Mean
wks.	*wks.*				
18	16 thru 19	46	0.1	65	0.0
26	24 thru 27	44	0.6	61	0.5
34	32 thru 35	42	1.7	57	2.0
42	40 thru 43	36	4.4	41	3.9
50	48 thru 51	31	6.3	42	5.3

content of the supplemented formula was approximately 320 Sherman-Chase Units" and of "the non-supplemented formula was 227 Sherman-Chase units" (14, pp. 732, 733, 739). There were 66 experimental and 51 control subjects: None was under study less than 2 months; over two-thirds were followed to prac-

tically the end of the first postnatal year. The mean age at eruption of the first tooth was 7.3 months for 59 infants of the experimental series and 7.5 months for 43 infants of the control series. Findings for mean number of teeth erupted at five different ages during the first year are given in Table V. In general, the means are similar for the 2 series in the second quarter of the year, higher for the experimental series in the third quarter, and higher for the control series in the fourth quarter. The results as a whole give no dependable support to the hypothesis of a relationship between age of tooth eruption and early addition of an extract of rice polishings to the milk formula.

In 1938, Gesell and Thompson (5) published an analysis of records for number of teeth present in the mouth at different ages during the first postnatal year. The records were gathered between 1927 and 1931 at the Yale Clinic of Child Development, New Haven, Connecticut. They were obtained on 107 infants—

TABLE VI

Number of Deciduous Teeth Erupted at Selected Ages

Data on New Haven "middle class" White infants examined 1927–31

AGE	MALES				FEMALES			
	N	Minimum	Mean	Maximum	N	Minimum	Mean	Maximum
wks.								
16	25	0	0.0	0	23	0	0.0	0
20	17	0	0.1	2	19	0	0.1	2
24	16	0	0.3	2	21	0	0.3	3
28	15	0	1.0	4	18	0	0.8	6
32	15	0	2.0	5	17	0	1.5	6
36	16	0	3.4	8	18	0	2.1	7
40	20	0	4.6	8	17	0	3.3	7
44	17	0	5.5	8	16	0	4.3	8
48	18	0	6.3	10	17	0	5.5	8
52	19	4	6.4	12	24	1	5.9	10

49 males and 58 females—described as "physically normal," full-term, healthy ("Several cases of decided malnutrition were excluded"), and from "single births" (5, pp. 28–31). The parents were American-born, of "northern European extraction," and "of the middle socio-economic status with respect to occupation, schooling, avocational interests, and home equipment" (5, p. 9). Examinations were scheduled at 4-week age intervals; "some of the subjects were regularly and repeatedly examined, while others were seen only once"; "a variation of but two days from the exact age for each examination was the rule" (5, pp. 5, 9). Table VI reproduces the findings. It will be seen that the mean number of erupted deciduous teeth is greater for males than for females at all ages after 6 months.

Tooth eruption during the first year of postnatal life was studied by Hamil, Reynolds, Poole and Macy (6) utilizing a sample of 427 Detroit infants (approximately two-thirds White and one-third Negro) fed a prescribed diet from early infancy. Collection of the data was carried out 1933–36 through the resources

of the Children's Fund of Michigan and the Children's Hospital of Michigan, Detroit. The subjects were infants of "indigent or near-indigent parents" living under home conditions: All were enrolled in the study before 3 months of age and 80% were followed over " a period of nine months or more" (6, p. 566). Their dietary regimen was "as rigidly controlled as possible"—visiting nurses "kept the mothers supplied with the essential materials for the formulas and supervised the care of the infants" (6, p. 567). The basal formula was "a mixture of evaporated milk, water and corn syrup . . . acidified by the addition of commercial dehydrated lemon juice of known ascorbic acid content" (6, pp. 567–8). After

TABLE VII

Eruption of Deciduous Teeth in Infants of Lower Classes Fed a Prescribed Diet

(Data amassed 1933–36 on Detroit White and Negro infants)

Mean number of teeth at successive ages in total sample and a subgroup

AGE GROUP		TOTAL SAMPLE		MILD SCURVY SUBGROUP	
Midpoint	Range	N	Mean	N	Mean
wks.	*wks.*				
10	8 thru 11	402	0.01		
14	12 thru 15	393	0.02		
18	16 thru 19	393	0.05	21	0.05
22	20 thru 23	380	0.15	20	0.10
26	24 thru 27	374	0.4	18	0.6
30	28 thru 31	345	1.0	19	1.0
34	32 thru 35	335	1.7	20	1.7
38	36 thru 39	328	2.6	20	2.3
42	40 thru 43	286	3.8	14	2.4
46	44 thru 47	278	4.5	16	4.1
50	48 thru 51	249	5.6	15	5.3
54	52 thru 55	105	6.2	6	6.0

Age (mos.) at eruption of first tooth in total sample

N	MEAN	S.D.	MINIMUM	MAXIMUM
354	7.3	1.7	1.7	11.5*

* Seven additional infants in the study were discharged at ages after 11½ months but "before first tooth erupted."

age 3 months, the prescribed daily dietary afforded 399 cc. evaporated milk, 1970–2050 International units of vitamin C, 150–250 Sherman-Chase units of vitamin B_1, and 0–810 U.S.P. units of vitamin D (less than 165 units for 31%, 250–600 units for 43% and 675–810 units for 26%). On the basis of "minute roentgen changes," 21 of the infants were diagnosed at different ages as having "mild" or "preclinical" scurvy—"9 of the 21 had some roentgen evidence of rickets at the time a diagnosis of mild scurvy was made" while "craniotabes or beading was recorded as a clinical finding in 17 of the 21 cases at some time before mild scurvy was evident" (6, p. 580). Eruption analyses were made for

both the scurvy subgroup and the total sample—the results are shown in Table VII. As may be confirmed from inspection of Table VII, selected findings for the total sample were: Earliest age of tooth eruption, 1.7 months; mean eruption in infants 7 months of age, 1 tooth; mean age at eruption of first tooth, 7.3 months; mean number of teeth erupted at ages 9 and 12 months, 3 and 6 respectively. Mean age for appearance of the first tooth in the mild scurvy subgroup was 8.1 months. The difference in eruption between the total sample and the mild scurvy subgroup was "not statistically significant."

Notations pertaining to "time of eruption of the teeth" were published by May and Wygant (10) on 48 "normal full-term" infants, 17 "weakling" infants, and 16 "premature" infants. "All of the infants came from the indigent class" (10, p. 356): Roughly two-thirds were White and one-third Negro. They were "enrolled as newborn infants in the Herman Kiefer Hospital, Detroit." "All were studied for a period of at least six months and many . . . for a year or more" (10, p. 358). Throughout the study, all subjects were "negative" for rickets, with the exception of 1 premature infant whose roentgenograms showed slight rachitic evidence around the age of 3 months. All were (a) fed irradiated evaporated milk assayed at 135 U.S.P. units of vitamin D per reconstructed quart and (b) "started on orange juice by the end of the second week" (10, p. 358). The percentages of each group lacking any eruption of teeth at ages 6 and 8 months are listed in Table VIII. For the "full-term" and "weakling" groups combined, there were 21 White males and 23 White females: At age 6 months, 33% of the males and 21% of the females showed eruption of 1 or more teeth. Individual variations among the "full-term" group included the following: A Negro female who erupted her first tooth at age 12 months, another who erupted her first tooth at $3\frac{1}{2}$ months and had all 20 erupted at 12 months; a White female with 8 teeth erupted by 7 months, another who did not erupt her first tooth until $7\frac{1}{2}$ months but had 12 erupted by 12 months; a White male who erupted 7 teeth in $1\frac{1}{2}$ months (first tooth at 6 months, 7 at $7\frac{1}{2}$ months), a Negro female who erupted 8 teeth in $2\frac{1}{2}$ months (first tooth at $6\frac{1}{2}$ months, 8 at 9 months), and a Negro male who erupted 8 teeth in 3 months (first tooth at $5\frac{1}{2}$ months, 8 at $8\frac{1}{2}$ months).

In 1942 Doering and Allen (4) published an analysis of eruption data for the deciduous teeth collected 1930–41 at the Center for Research in Child Health and Development, Harvard School of Public Health. The subjects were full-term "clinically normal" infants born at the Boston Lying-in Hospital. They were "of American or North European parentage"—roughly half of Irish descent. Information on occupation of the fathers yielded around 30% unskilled or semiskilled, 50% skilled, and 20% managerial or professional. Examinations were made "at birth, at three months' intervals up to one year, and at six months' intervals thereafter" (4, p. 113): "The limits of variation in the age at examination" were 7 days up to 2 years and 10 days at older ages. The examinations included comprehensive medical evaluations and afforded the parents both general and individualized "advice as to feeding and care" (4, p. 31). "A tooth was considered erupted if it had ruptured the membrane of the gum and was in sight"

(4, p. 113). Selected quantitative results are presented in Table IX. Utilizing values from this table together with the results from further analyses, Doering and Allen deduced the following findings:

1. "No tooth in any child had erupted at three months of age. . . all children examined at 15 months had at least one tooth" (4, pp. 113, 120). At intermediate ages, the percentages of children with no teeth erupted were 80 (6 months), 20 (9 months), and 2 (12 months).

2. Of the 223 children examined at 2½ years of age, 71% showed eruption of the full complement of deciduous teeth: of the 218 examined at 3 years of age, only 4 % "failed to have all their teeth" (4, p. 115).

3. "In general the deciduous teeth erupt in the following order: central incisors, lateral incisors, first molars, cuspids, and second molars" (4, p. 115). For incisor teeth, the lower centrals tended to precede the upper centrals, and the upper laterals the lower laterals.

4. "From the original records it was noticed that in 13 males and in 14 females out of approximately 110 males and 110 females, certain discrepancies in order of eruption occurred. Most frequently in this small group the lower lateral incisors erupted after the first molars and at times the cuspids appeared before the first molars. Occasionally all the mandibular teeth were present when there were no maxillary cuspids or second molars present" (4, p. 115).

TABLE VIII

Deciduous Dentition in Infants of Lower Classes Fed Irradiated Evaporated Milk

Data collected in Detroit on White and Negro infants

	AGE 6 MOS.		AGE 8 MOS.	
	N	Percentage lacking eruption	N	Percentage lacking eruption
Premature (birthwt. less than 5½ lbs.)	16	100	10	80
Weakling (birthwt. 5½ to 6½ lbs.)	17	70	10	50
Full-term (birthwt. 6½ to 10 lbs.)	48	70	31	32

5. For 95% of the subjects, the period during which the deciduous dentition erupted varied between 18 months and 30 months. One subject (male) "erupted 20 teeth in less than 12 months before he was 18 months old" (4, p. 120); another subject (female) had an eruption period of almost 3 years.

6. The mean number of teeth erupted was slightly higher for males than for females at all ages from 6 to 30 months. Largest sex differences were obtained at 9 and 12 months.

7. Individual differences in number of teeth present in the mouth was greatest at 12 and 18 months. Also, more teeth were found to erupt "between the ages of 12 and 18 months. than at any other time" (4, p. 115).

8. "The tooth with the greatest variation in age of eruption is the second molar. One child may have this tooth at 18 months, but another may not have it at 3 years" (4, p. 117).

A second 1942 study on "eruption of deciduous teeth" was reported by Robinow, Richards and Anderson (17). The subjects were "presumably normal, healthy, White children" enrolled for seriatim study with the Samuel S. Fels Research Institute, Yellow Springs, Ohio. They were "from families of average or better than average economic status . . . about equally urban and rural" (17, p. 328). Examinations were made "every month up to 6 months, every

TABLE IX

Eruption of Deciduous Teeth in Boston, "Middle Class," Clinic Supervised Children

Number of teeth erupted at different ages

AGE	N	MEAN	S.D.	MINIMUM	PERCENTILES			MAXIMUM
					25	50	75	
Males								
mos.								
6	127	0.4	0.9	0	0	0	0	4
9	131	3.4	2.3	0	2	4	6	8
12	131	6.0	1.9	0	5	6	8	11
18	118	12.5	3.0	5	11	12	16	20
24	113	16.8	2.2	11	16	16	19	20
30	110	19.2	1.4	16	19	20	20	20
36	107	19.9	0.6	16	20	20	20	20
Females								
6	143	0.3	0.8	0	0	0	0	5
9	132	2.8	2.4	0	1	2	4	8
12	137	5.6	2.3	0	4	6	7	12
18	123	12.4	2.7	4	12	12	14	16
24	112	16.6	2.2	12	16	16	18	20
30	113	19.1	1.6	12	18	20	20	20
36	111	19.9	0.5	16	20	20	20	20

Percentage of children with right and left teeth of each type

TEETH	AGE IN MONTHS						
	6	9	12	18	24	30	36
Males							
Lower first incisors	17	75	97	100			
Upper first incisors	2	52	90	100			
Upper second incisors		26	68	96	100		
Lower second incisors		5	28	92	99	100	
Upper first molars			1	80	100		
Lower first molars				78	100		
Upper canines			1	35	91	100	
Lower canines				31	89	100	
Lower second molars				3	28	82	97
Upper second molars				2	26	75	95
Females							
Lower first incisors	13	68	95	100			
Upper first incisors	1	40	83	100			
Upper second incisors		14	53	94	100		
Lower second incisors		8	26	93	100		
Upper first molars			3	82	100		
Lower first molars			2	81	100		
Upper canines				33	88	97	100
Lower canines				27	88	99	100
Lower second molars				1	28	78	99
Upper second molars				1	25	75	96

$1\frac{1}{2}$ months until 18 months, every 2 months until 3 years, every 3 months until 6 years. . . . In addition, the mothers were asked to record the date of eruption for each tooth" (17, p. 127). "Teeth were considered erupted as soon as part of the crown had pierced the gum" (17, p. 127). "Eruption ages for all 20 deciduous teeth were obtained on 64 children" (31 males, 33 females; 1,280 teeth), and eruption ages for another 700 deciduous teeth on an additional 175 children. "The figures for right and left homologous teeth were combined" (17, p. 127). Table X affords the numerical findings. Discussion of findings treated order of tooth eruption and sex differences in eruption:

TABLE X

Eruption of Deciduous Teeth in Ohio Children of Middle and Upper Classes

	MALES		FEMALES		BOTH SEXES
	Mean	S.D.	Mean	S.D.	Mean
Age at eruption (mos.) for pairs of homologous teeth					
Lower central incisors	7.3	1.6	7.8	2.1	7.6
Upper central incisors	9.1	1.5	9.6	2.0	9.4
Upper lateral incisors	10.4*	2.4	11.9	2.7	11.1
Lower lateral incisors	13.0	2.8	13.8	3.6	13.4
Upper first molars	16.0	2.3	15.7	2.3	15.8
Lower first molars	16.2	1.9	15.6	2.2	15.9
Upper canines	18.9	2.7	20.1	3.2	19.5
Lower canines	19.3	2.9	20.2	3.4	19.8
Lower second molars	25.9	3.8	27.1	4.2	26.5
Upper second molars	27.6	4.4	28.4	4.3	28.0
Number of teeth erupted at each of eight ages					
6 months	0.4	0.9	0.4	0.8	0.4
9 months	3.1	1.7	2.2	2.0	2.7
12 months	6.5	1.9	5.6	2.6	6.1
18 months	12.9	2.5	12.2	2.6	12.6
24 months	17.2	1.7	16.2	2.2	16.7
30 months	19.4	1.4	18.6	1.6	19.0
36 months	20.0	0.4	19.9	0.7	20.0
42 months			20.0	0.0	20.0

* 10.5 in another table.

1. "Boys were slightly advanced over girls in the eruption of all teeth except the first molars" (17, p. 133). The eruption of incisor and canine teeth was more variable in females than in males.

2. The characteristic sequence of eruption was incisors (lower first incisors, upper first incisors, upper second incisors, lower second incisors); first molars; canines; and second molars (lowers before uppers). The investigators stated: "Most of our children followed this pattern though the variations were quite common. Children, the majority of whose teeth erupted late, tended to show more variations from the above order than early eruptors. Changes in the order

were most frequently brought about by the variability of the lateral incisors" (17, pp. 129–130).

Meredith (12), in 1943, analyzed data for eruption of the deciduous teeth obtained at quarter-year ages from 3 months to 2 years. The data were gathered 1938–42 on 225 White infants—112 males and 113 females—enrolled for developmental examinations at the well-infant laboratory of the Iowa Child Welfare Research Station, University of Iowa. A tooth was recorded as erupted if any part of it had perforated the gingiva. Upwards of 90 per cent of the subjects

TABLE XI

Deciduous Dentition at Each of Eight Ages

(Data collected 1938–42 on Iowa City infants of middle and upper classes)

Means and extreme values for number of erupted teeth

AGE	MALES				FEMALES			
	N	Mean	Minimum	Maximum	N	Mean	Minimum	Maximum
mos.								
3	38	0.0	0	0	36	0.1	0	2
6	53	0.7	0	4	53	0.6	0	4
9	43	3.6	0	8	54	3.3	0	8
12	36	6.8	2	12	31	6.1	0	12
15	22	10.4	6	16	33	9.2	4	15
18	32	12.4	7	16	36	12.1	7	16
21	31	15.1	9	20	28	14.7	10	20
24	19	16.9	14	20	15	16.4	10	20

Percentage of subjects with different numbers of erupted teeth

	MALES					FEMALES				
	0	1–4	5–8	9–14	15–20	0	1–4	5–8	9–14	15–20
3	100					97	3			
6	64	36				68	32			
9	14	51	35			9	59	32		
12		8	86	6		3	23	68	6	
15			41	45	14		6	42	49	3
18			13	59	28			11	64	25
21				35	65				39	61
24				16	84				13	87

were of northwest European ancestry. About 25 per cent were examined at one age, 35 per cent at two ages, and 40 per cent at three or more ages. Approximately 50 per cent of the fathers were engaged in professional or managerial occupations and 50 per cent in skilled or semiskilled occupations. The findings from two types of analysis are displayed in Table XI.

Additional findings were:

1. The number of teeth erupting within a given period varied markedly for different individuals. The maximum eruptions found to occur within 3 selected periods were as

follows: Two subjects erupted 16 teeth within a period of 1 year (a female, no teeth at 6 months, 16 at 18 months; a male, no teeth at 9 months, 16 at 21 months); 3 other subjects erupted 14 teeth within a period of 9 months (a female, 6 teeth at 1 year, 20 at 21 months; 2 males, 2 teeth at 6 months, 16 at 15 months); another 2 subjects erupted 10 teeth within a period of 6 months (a female, 2 teeth at 6 months, 12 at 1 year; a male, no teeth at 9 months, 10 at 15 months).

2. The predominant eruption sequence was incisors—lower first incisors, upper first incisors, upper second incisors and lower second incisors; first molars; canines; and second molars. Exceptions to this sequence included eruptions of (a) upper first incisors before lower first incisors, (b) upper second incisors before upper first incisors, (c) lower second incisors before upper second incisors, (d) lower first molars before incisors—one female subject was born with the lower first molars erupted, (e) upper and lower first molars before upper second incisors, (f) upper and lower first molars before lower second incisors, (g) lower canines before second incisors or first molars, (h) upper canines before lower second incisors, (i) lower canines before upper or lower first molars, (j) upper and lower canines before upper first molars, and (k) upper and lower second molars before canines.

Deciduous eruption materials for a 1944 investigation by Sandler were amassed from "examination of 1,962 White children of fairly low economic status but under regular nutritional and medical supervision" (18, p. 146). The subjects resided in Brooklyn, New York, and were enrolled at 7 "well-baby clinics . . . in the Brownsville and Bushwick Health Districts" (18, p. 140). Data were obtained on all White children attending the clinics during the fall and winter of 1941–42. "The definition of an erupted tooth was limited to its appearance through the gums" (18, p. 140). Table XII brings together selected results from statistical reduction. ". . . no child under 4 months of age had a tooth erupted . . . all of the children over 34 months of age had all of their deciduous teeth erupted" (18, p. 141). The oldest age at which no teeth were found to have erupted was 13 months: the youngest age at which all 20 teeth were erupted was also 13 months. Four teeth were present in children as young as 5 months and as old as 17 months, 8 teeth in children aged 9 months and 24 months; 12 teeth in children 11 months and 25 months; 16 teeth in children 11 months and 32 months. Sandler reported finding no systematic tendency for the teeth of the right side to erupt earlier than those of the left, or vice versa.

Mean ages for eruption of the first incisor and of the full deciduous complement were reported in 1945 by Rhoads, Rapoport, Kennedy and Stokes (16). Collection of the data was carried out 1936–42 through the Out-Patient Department of the Children's Hospital of Philadelphia. The subjects were 233 full-term male children—134 White and 99 Negro—residing in families "of a low socio-economic level" and given dietary supervision from an average age of 6 postnatal weeks. Children were "classed as Negro where they had any known trace of Negro blood" (16, p. 437): The White subjects were "in large proportion of northern European stock, with approximately one-fourth of Italian descent" (16, p. 416). All of the subjects were followed to 2 years of age, 208 to 3 years, and 153 to 4 years. Examinations were made once a month during the first year and every 2 months thereafter. From the time of the first examination all subjects were prescribed orange or tomato juice and an evaporated milk formula with added carbohydrate. Four dietary subgroups were formed—

TABLE XII

Eruption of Deciduous Teeth in New York Children of Lower Classes

Order and age (mos.) of eruption of teeth

	EARLIEST AGE ERUPTION OBSERVED	PERCENTILES			LATEST AGE ERUPTION LACKING
		25	50	75	
Lower first incisor	4	6.1	7.8	9.4	17
Upper first incisor	5	8.1	9.6	11.0	15
Upper second incisor	6	9.9	11.5	13.0	21
Lower second incisor	6	10.5	12.4	14.3	27
Upper first molar	8	13.4	15.1	16.8	27
Lower first molar	8	13.8	15.7	17.6	27
Lower canine	8	16.2	18.2	20.0	29
Upper canine	8	16.3	18.3	20.2	29
Lower second molar	8	23.5	26.0	28.3	34
Upper second molar	8	23.7	26.2	28.5	34

Number of teeth erupted at different ages

AGE GROUP		N	MINIMUM	PERCENTILES			MAXIMUM	MEANS		
Midpoint	Range			25	50	75		Male	Female	Both sexes
mos.	*mos.*									
Under 4 months		330	0	0	0	0	0			
5	4.5– 5.5	86	0	0	0	0	4	0.4	0.2	0.3
6	5.5– 6.5	95	0	0	0	2	6	0.8	0.6	0.7
7	6.5– 7.5	77	0	0	0	2	6	1.4	0.8	1.2
9	8.5– 9.5	73	0	1	2	4	9	3.2	2.8	3.0
12	11.5–12.5	56	0	4	6	8	17	6.6	5.8	6.2
15	14.5–15.5	66	3	7	9	12	16	10.2	8.2	9.2
18	16.5–19.5	124	4	12	13	16	18	12.8	13.2	13.1
21	19.5–22.5	119	4	14	16	16	20	15.6	15.4	15.5
24	22.5–25.5	110	8	16	16	18	20	16.5	16.7	16.6
30	28.5–31.5	70	12	18	20	20	20	19.0	19.0	19.0
Over 34 months		110	20	20	20	20	20	20.0	20.0	20.0

TABLE XIII

Mean Age (mos.) at Eruption of First Incisor and Full Deciduous Complement

Data for Philadelphia males of "low income families" on four prescribed diets

GROUP	WHITE MALES				NEGRO MALES			
	First incisor		20 teeth		First incisor		20 teeth	
	N	Mean	N	Mean	N	Mean	N	Mean
I	48	7.5	45	28.0	32	7.8	30	28.7
II	24	8.0	24	27.2	17	8.2	17	28.1
III	20	8.3	18	28.9	19	8.5	19	27.8
IV	42	8.0	41	28.8	31	8.7	31	28.4
Groups I–IV	134	7.9	128	28.2	99	8.3	97	28.3

the objective in this was to determine the influence of supplements of vitamins D, A, and B complex on the deciduous dentition of children fed evaporated milk as their sole milk supply. Groups I, II, and III received "110 U.S.P. units of vitamin D daily in the form of irradiated evaporated milk"; Groups II and III also were given approximately 2,250 U.S.P. units of vitamin A daily in 10 drops of carotene; and Group III received roughly 250 units of vitamin B_1 and 250 Sherman units of vitamin B_2 daily through the medium of brewer's yeast powder. Group IV was fed "non-irradiated evaporated milk plus 3 teaspoons of cod-liver oil daily" (16, p. 418). For all groups, visits were made to the homes every 2 weeks "in order to deliver the evaporated milk and vitamin supplements, and to keep in touch with the home care of the child" (16, p. 417). At 6 months of age the common dietary included "banana, cereal, and pureed vegetables and fruits, and at 1 year, potato, meat and egg" (16, p. 417). "Incidence of infection . . . was approximately the same for all groups" (16, p. 419). The dental examinations were made by Drs. Norman Weiselberg and Albert Cohen. Table XIII itemizes the findings.

It was concluded:

1. "Whether the child was fed 110 units of vitamin D in irradiated evaporated milk or 1,500 units in cod-liver oil apparently made no difference in the age at eruption of teeth, nor did supplementation with carotene or yeast" (16, p. 447).

2. ". . . there was no striking difference in the eruption times of the White and Negro children" (16, p. 448).

Stearns and others (21) studied deciduous tooth eruption in White infants especially housed for research on mineral and vitamin metabolism at the Children's Hospital, University of Iowa. "The date of the appearance of each tooth was a part of the daily records kept for each infant by the ward nurses. The day on which any of the incisal or occlusal portion of a tooth appeared through the gum was recorded as the date of eruption" (21, p. 506). Over the period 1930–45 dental records were secured on 43 males and 18 females under continuous observation from early postnatal life to at least 9 months of age. The infants were fed controlled diets built around a whole or evaporated milk mixture containing 6% added carbohydrate, and usually acidified with lactic or citric acid. One ounce of orange juice daily was given to infants under 4 months and 2 ounces to older infants. Egg yolk or iron citrate was added to the daily diet at 3 to 4 months, sieved vegetables at 5 months and sieved fruits at 6 months. The daily intake of vitamin D varied from less than 100 U.S.P. units for some infants to upwards of 4,000 U.S.P. units for others. Analyses were made on the total group of males and females and on 2 dietary-health subgroups. One subgroup consisted of 14 males and 8 females considered to have "superior" dietary and health protocols: Each infant ingested 300 to 400 U.S.P. units of vitamin D daily and was free from both severe acute and mild chronic illnesses. The remaining 29 males and 10 females constituted the other ("poorer") subgroup. In the first 4 sections of Table XIV are findings obtained utilizing the total sample, and in the last section findings for each of the 2 dietary-health subgroups. A few of the results which may be drawn from this table are: (1) tooth eruption

TABLE XIV

Eruption of Deciduous Teeth in White Infants on Controlled Dietary Intakes

Number of teeth at ages 6 and 9 months

SEX	AGE	N	MEAN	PERCENTAGE OF INFANTS WITH:				
				0	1–2	3–4	5–6	7–8
	mos.							
Females	6	18	0.2	89	11			
Males	6	43	0.8	60	33	5	2	
Females	9	18	2.9	11	56	11	16	6
Males	9	43	3.8	12	23	30	21	14

Age (mos.) at eruption of first tooth

SEX	N	MINIMUM	PERCENTILES:			MAXIMUM
			25	50	75	
Females	18	5.0*	6.4	7.3	7.8	10.0+†
Males	43	4.0	5.4	6.7	8.0	11.2‡

Individual differences in the first, third and sixth teeth erupted

PERCENTAGE OF INFANTS OF BOTH SEXES ERUPTING:	ORDER OF ERUPTION		
	First tooth	Third tooth	Sixth tooth
Lower first incisor	96	2	3
Upper first incisor	2	72	25
Upper second incisor	2	20	53
Lower second incisor		6	19
Number of subjects	58	49	36

Individual differences in order of eruption of lower central incisors

	RIGHT TOOTH FIRST BY:		BOTH TEETH TOGETHER (LESS THAN 1 WEEK APART)	LEFT TOOTH FIRST BY:	
	4 to 6 wks.	1 to 3 wks.		1 to 3 wks.	4 to 8 wks.
Percentage	12	18	45	21	4

Eruption of teeth in 2 dietary-health subgroups

GROUP	NUMBER		MEDIAN ERUPTION AGE FOR FIRST TOOTH		MEAN NUMBER OF TEETH AT AGE 9 MONTHS	
	Males	Females	Males	Females	Males	Females
			mos.	*mos.*		
"Superior"	14	8	5.6	7.3	4.7	2.9
"Poorer"	29	10	7.1	7.4	3.4	2.9

* The youngest age of tooth eruption for an infant in this research laboratory is 2.4 months. The subject was a female available for study until 6 months of age.

† Two females left the study before erupting any teeth—one at 9 months and the other at 10 months.

‡ For 1 male, it is not known at what age after 9 months the first tooth pierced the gum.

tended to occur earlier in males than in females; (2) number of erupted teeth at age 9 months varied from 0 to 8 for infants of each sex; (3) there was no systematic tendency for the lower left first incisor to erupt earlier than the lower right, or *vice versa*; (4) the sixth tooth to erupt was an upper second incisor in 53% of the infants, an upper first incisor in 25%, and a lower second incisor in 19%; (5) male infants classified as constituting a "superior" dietary-health subgroup showed unusually early tooth eruption.

GENERALIZATIONS

The foregoing investigations on eruption of the deciduous dentition in North American children yield the following generalizations:

1. Rarely do infants erupt teeth before the end of their fourth postnatal month. Reported instances of tooth eruption at younger ages include a White female born with 2 teeth (12), a White or Negro infant erupting a tooth at 1.7 months (6), 3 White and/or Negro infants erupting their first teeth at 2 months (1), a White female erupting a tooth at 2.4 months (21), an American Indian female with 2 teeth erupted at 2.5 months (8), a White infant of each sex showing eruption of a tooth at 3 months (22), and a Negro female erupting a tooth at 3.5 months (10). Aggregating the relevant samples of White infants studied (5, 18, 21, 2, 4, 7, 10, 12, 17, 22), it is estimated that the frequency of tooth eruption prior to 4 months of age is less than 1%.

2. The mean age for eruption of the first tooth is 7½ months. This is the exact composite mean derived by pooling the data on 1,095 infants—about 70% White and 30 per cent Negro—available from 5 investigations (1, 6, 16, 21, 22). The most diverse averages reported for eruption of the first tooth are 5.6 months and 8.7 months. The latter was obtained on 31 Negro males prescribed a diet of "evaporated milk plus 3 teaspoons of cod-liver oil daily"; the former on 14 White males living under controlled conditions, ingesting 300–400 U.S.P. units of vitamin D daily, and affording health protocols "negative" for severe acute and mild chronic illnesses.

3. A few infants do not begin to erupt teeth until early in the second postnatal year. This may be confirmed by reference to the records of first eruption at 13 months (1, 18), during the first quarter of the second year (4, 12), and at 15 and 16 months (22). Combining the pertinent materials accumulated in 8 studies (1, 4, 5, 6, 10, 12, 18, 22), it appears that approximately 1% of White infants erupt their first tooth after 1 year of age. Incidentally, after 2 months allowance is made for the amount of prematurity, all of the Dionne quintuplets are found to have erupted teeth by the end of the first year (3).

4. At 6 months of age, approximately 1 infant in 3 is characterized by 1 or more erupted teeth. In a series of 576 White infants, roughly two-thirds have been found to lack tooth eruption and one-third to exhibit from 1 to 6 erupted teeth (4, 10, 12, 18, 21). Obviously, with a distribution of this type the mean and median do not coincide. The median is zero, *i.e.*, the typical infant age 6 months has no erupted teeth. The mean, as derived from records for number of erupted teeth on more than 1,100 White and Negro infants (4, 5, 6, 12, 17, 18, 21), is 0.4.

5. At age 9 months, the average infant has 3 erupted teeth. Three is the median for 263 "middle class" White infants given pediatric supervision (4) and the mean for 670 White infants of varying socio-economic status and health care (4, 5, 12, 17, 18, 19, 21). The usual range of individual variation is from 0 to 8 teeth (4, 5, 12, 21): One investigator reports a maximum of 9 teeth (18). About 10% of White infants have no teeth, 80% between 1 and 6 teeth, and 10% more than 6 teeth (4, 12, 18, 21). For each sex separately, the means are 3.4 erupted teeth in 350 males and 2.7 in 320 females (4, 5, 12, 17, 18, 19, 21): Among those infants erupting over 6 teeth by 9 months, there are roughly 3 times as many males as females (12, 21). The extreme means reported on males are 2.6 for 14 "Sicilian infants from the lower East Side of New York" (19) and 4.7 for 14 infants living under controlled conditions and having "superior" histories for nutrition and health (21). The female means are more homogeneous.

6. In infants 1 year of age, the number of erupted teeth is rarely less than 2 or more than 10. A few infants have no teeth (4, 12, 18) and a few 12 teeth (4, 5, 12) or more—examples of more than 12 erupted teeth are a White infant with 17 (18) and a Negro infant with 20 (10). Fifty per cent of 1-year-old infants have between 4 and 8 teeth (4, 18). Composite means are 6.0 for 700 infants of both sexes (approximately 90% White and 10% Negro), 6.3 for 260 White males, and 5.7 for 270 White females (4, 5, 6, 12, 17, 18).

7. The typical, or median, number of erupted teeth is 12 in children 18 months of age and 16 in children 2 years of age. For White infants age 18 months, about 10% have 4 to 8 teeth, 85% 9 to 16 teeth, and 5% 17 to 20 teeth (4, 12, 17, 18). Composite mean values at this age are 12.7 for 245 males and 12.5 for 255 females (4, 12, 17, 18). White infants age 2 years are dispersed with roughly 15% having 8 to 14 teeth, 60% 15 to 18 teeth, and 25% 19 or 20 teeth (4, 12, 18, 22). Composite means at 2 years are 16.9 for 260 males and 16.5 for 250 females (4, 12, 15, 17, 18, 22).

8. At 2½ years of age, 30% of White children have 12 to 19 erupted teeth and 70% the full deciduous complement. The mean number of teeth at this age is 19.2 for males and 19.0 for females (4, 17, 18): The typical (median) child has 20 teeth (4, 18). Data for exact age at eruption of the last deciduous tooth have yielded means of 28.2 months on 128 White males and 28.3 months on 97 Negro males (16). Roughly 90% of children complete eruption of the deciduous dentition between 2 and 3 years of age. Instances of completion earlier than 2 years include a Negro child with 20 teeth at 12 months (10), a White child with 20 teeth at 13 months (18), a White child with 20 teeth at 18 months (4), 2 American Indian children with 20 teeth at 20 months (8), and White children with 20 teeth at 21 months (12, 18). Individuals still lacking eruption of the full deciduous complement have been observed at 36 months (4, 17) and 37 months (15, 19). When deductions of 2 months are made to correct for the amount of prematurity, 4 of the Dionne quintuplets are found to have erupted the full deciduous complement by 36 months and 1 (Yvonne) after 38 months (3).

9. There are wide individual differences in the timing of eruption of deciduous teeth: Some children erupt a given tooth early, others late; some erupt the full deciduous complement in a short period, others spread their 20 eruptions over an

extended time interval. From the standpoint of number of teeth present in the mouth at different ages, variation is greatest during the first half of the second year. Records manifesting the maximum scatter attainable (*i.e.*, no erupted teeth in one child and a full complement in another) have been obtained on Negro subjects age 12 months (10) and on White subjects age 13 months (18). The standard deviation is largest around 18 months (4, 17): Minimum and maximum records for number of erupted teeth at this age are 4 and 20 (4). Turning to consideration of the age span during which given numbers of teeth are found, 4 teeth have been reported in children as young as 5 months and as old as 20 months, 8 teeth in children 7 and 24 months, 12 teeth in children 11 and 30 months, and 16 teeth in children 11 and 37 months (10, 11, 18, 19). The duration of the deciduous eruption period varies from less than 1 year to almost 3 years (4, 10): For over 90% of children the span of time within which the first dentition erupts is between 18 and 30 months (4). Instances are on record of children erupting 7 teeth in 1.5 months, 12 teeth in 6 months, and 20 teeth in 9 months (10, 12).

10. The usual order of eruption for the deciduous teeth is incisors, first molars, canines, second molars. In greater detail, the characteristic eruption sequence has been established as lower first incisors, upper first incisors, upper second incisors, lower second incisors, first molars (upper and lower), canines (upper and lower), lower second molars, upper second molars (2, 4, 17). It follows that the 6 erupted teeth of the typical child age 1 year are the lower first incisors and the upper first and second incisors. Similarly, the 16 erupted teeth of the typical child age 2 years are the first and second incisors, the first molars, and the canines. For about 95% of individuals the first tooth to erupt is a lower first incisor (21): Occasionally eruption begins with an upper first incisor, upper second incisor, or first molar (3, 12, 21). The third tooth to erupt, while ordinarily an upper first incisor, is an upper second incisor in approximately 20% of infants and a lower second incisor in roughly 5% (21). Additional exceptions to the predominant pattern include the eruption of first molars before second incisors, canines before second incisors, canines before first molars, and second molars before canines (3, 4, 12, 17). Obviously, when these exceptions are elaborated for specific teeth or tooth pairs an extensive list of variations accrues (3, 4, 12). One study reports: "Occasionally all the mandibular teeth were present when there were no maxillary cuspids or second molars" (4). Another, after noting that variations in the sequence of eruption are "common," states: "Children, the majority of whose teeth erupted late, tended to show more variations . . . than early eruptors" (17).

11. *Sex:* At all ages from 9 months to 2 years teeth tend to erupt earlier in males than in females.[3] *Race:* While materials on Negro subjects are limited, it appears there is "no striking difference" in average age of tooth eruption for

[3] This finding stands in sharp contrast with certain statements in a recent book on sex differences. To quote: "It is entirely natural for the little girl to be ahead. . . in teething." And again, ". . . the girl usually leads in every phase of tooth development" (Scheinfeld, Amram, *Women and men*, 1944, pp. 41, 47–48).

White and Negro children (10, 14, 16). The few observations on American Indian children apparently conform to the same general eruption sequence as followed by White children, but suggest an earlier timing of eruption. *Diet and disease:* No association has been found between the age of eruption of deciduous teeth and early addition to the diet of vitamin B through the medium of brewer's yeast powder or a water-soluble extract of rice polishings (14, 16). One investigation obtained "no difference in the age at eruption of teeth" between 150 children fed 110 U.S.P. units of vitamin D daily in irradiated evaporated milk and 70 children fed 1500 U.S.P. units daily in cod-liver oil (16). In another study it was found that a group of 14 male infants ingesting 300–400 U.S.P. units of vitamin D daily, and also having superior records for freedom from illness, erupted their incisor teeth at ages earlier than those reported on any other group (21).[4] The age of tooth eruption in a small group of infants developing mild scurvy and mild (subclinical) rickets was found not to differ from that for healthy infants (6). *Prematurity:* There are a limited number of observations tending to support the hypothesis that tooth eruption during the first postnatal year occurs later in infants born prematurely than in infants born "at term" (3, 10).

SUMMARY

This paper treats the order and age of eruption of the deciduous teeth in North American children. Its purpose is twofold: To assemble the available research materials on the problem and to present a synthesis of these materials. The findings from 22 investigations (including 2 not previously reported) are reviewed. These findings are then ordered and integrated in a series of statements which epitomize present knowledge on the problem.

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[4] Without minimizing the need for further study of the relationship between intake of vitamin D and age of tooth eruption, it is pertinent to mention the present hypothesis of Drs. Philip C. Jeans and Genevieve Stearns. For many years of controlled research covering the first year of postnatal life, these authors have formulated the following view: a. 300–800 U.S.P. units of vitamin D daily promotes accelerated rate of growth in stature, increased calcium and phosphorus retentions, and early eruption of teeth; b. less than 125 units is ordinarily insufficient for "maximum effect"; and c. 1500–2000 units usually has a "depressing (toxic) action." In terms of this view there is no lack of harmony between the finding of early tooth eruption for infants receiving 300–400 units (maximum effect) and the findings of later ages of eruption both for infants fed 110 units (increasing effect but not maximum) and for those fed 1500 units (decreasing effect).

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STANDARDS OF VARIATION IN THE ERUPTION OF THE FIRST SIX PERMANENT TEETH

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The establishment of norms and standards for various anthropometric variables pertaining to the teeth of children is still quite incomplete. Among the standards that still are lacking are those relating to the eruption of teeth. Although it can be argued that such standards would not fit perfectly any given child, it is self-evident that exact knowledge of the usual ranges of variation encountered would furnish convenient frames of reference for numerous biometric studies of individual children and groups of children. Such standards would be of value in attempts to interpret various reports which contain references to the clinical emergence of the teeth.

Several studies of rachitic and non-rachitic children have established the fact that at least one deficiency disease is generally accompanied by retardation of dental development. These studies remind the investigator of the necessity of being able to gauge tooth eruption in terms of small fractions of a year, rather than in terms of whole years. Therefore, since the physiologic processes which result in tooth emergence take place at a rapid rate when they do occur, it is imperative that the standards used are even more accurate than those which have to do with certain other growth phenomena, such as increases in body height and weight. A continuation of nutritional studies, as well as the development of broader programs dealing with constitutional types or a variety of pathological conditions, requires the establishment of best possible criteria for evaluating observations made on the teeth.

It became evident early in the course of this bibliographic study that presently available literature did not make the task of proper colligation easy. Not only were many of the best papers dealing with the time of eruption of the permanent teeth published in journals that are difficult of access, but the chief objective of the study made it absolutely necessary to review these papers in great detail. It was obvious that the standards derived would be of value only if they were based upon source material which met certain definite and reasonably exacting requirements.

Selection and standardization of data on the ranges of variation.

There were two main problems to be solved in attempting to summarize existing data on tooth emergence. The first of these had to do with the determination of the shapes of the frequency curves which give the cumulated percentages of erupted teeth at various age levels. The second important task was the selection of reports that could be used for calculating the mean and median ages of eruption of individual classes of teeth.

The first problem could be attacked only by determining what reports furnished figures that could be reduced to graphic form for describing

chronologic variations in the eruption of individual teeth. The reports selected had to furnish data covering at least one half of the age range during which a particular tooth crown is likely to make its debut into the external environment. The reports utilized for this purpose did not have to contain a definition of the term "eruption." It seemed safe to assume, after comparing several series of graphs representing data on teeth in various stages of eruption (i.e., graphs for teeth that are "just erupting," "in any stage of eruption," "fully erupted," etc.), that the shapes of the curves are not dependent to any appreciable degree upon the investigator's exact criteria of "eruption." This must not be taken to mean that careful studies in the future will not reveal statistical differences in the ranges of variation for different developmental stages of tooth emergence. The present study indicates only that if such differences do exist, they are of relatively small magnitude and of negligible importance in many biometric analyses. Therefore, the data were graphed on the presupposition that the average intervals between various stages of supragingival eruption are of equal magnitude at all age levels in a given group of children.

Lack of standardization of methods of recording and publishing data on eruption made the task of graphing the selected material a tedious process. Some authors, for instance, publish their figures for the right and left teeth separately, without presenting averages for the two sides. Some give the data in terms of the number of teeth observed, without computing any percentages. Some furnish the data for the two sexes separately, while others do not. Very few of the authors summarize their statistical material in a convenient graphic form. Much of the graphic material that is available is difficult of utilization on account of the poor planning or the diminutive size of the published graphs. The facts mentioned above give the reader some concept of the difficulties involved in forming a logically coherent assemblage of existing data on tooth eruption. The amount of work involved in preparing such data for further analysis can be appreciated even better if one remembers that from 21 to 29 separate standardization processings had to be completed for each one of the six permanent teeth discussed in this report.

The reports utilized for determining the frequency curves mentioned above varied in number from 14 for the mandibular first incisor to 18 for the maxillary first incisor. The sources of graphed data are listed in greater detail in Table I.

The problem of chronologic age.

The second main problem had to do with the determination of the chronologic ages of tooth emergence. Before this problem could be attacked successfully, it was necessary to find out what reports dealt with tooth eruption in an unambiguous manner. The difficulties encountered here were threefold.

In the final computations only those reports could be utilized which contained a reasonably clear indication of the meaning of the term "eruption" as used by the author. This seemingly simple requirement put the reviewer to much inconvenience, as very few of the publications provide the reader

TABLE I

A list of authors whose publications contain data that can be used for determining the cumulated percentages of teeth in any stage of eruption at various age levels.

AUTHOR, *with specification of data used*	FIRST MOLARS		FIRST INCISORS		SECOND INCISORS	
	Max.	*Mand.*	*Max.*	*Mand.*	*Max.*	*Mand.*
Berten (1895)	BG	M[1]	BG	M[1]	BG	BG
Bunting (1909)	M	M	M	M	M	M
Cartwright (1857)	M	M	none[2]	none[2]	none[2]	none[2]
Cattell (1928)	BG	BG	BG	BG	BG	BG
Chérot (1898)	M[1]	M[1]	M[1]	M[1]	M[1]	M[1]
Cohen (1928)	BG	BG	BG	BG	BG	BG
Cohen (1936)	M[1]	M[1]	M[1]	M[1]	M[1]	M[1]
Degerböl (1929-32)	insuf.	insuf.	BG	insuf.	BG	BG
Ekman (1938)						
rural children	insuf.	insuf.	BG	insuf.	BG	BG
Helsinki pub. school children	BG	BG	BG	BG	BG	BG
Förberg (1901)	insuf.	insuf.	BG	insuf.	BG	BG
James & Pitts (1912)	M	M	M	M	M	M
King (1940)	M	M	M	M	M	M
Klein, Palmer & Kramer (1937)	BG	BG	BG	BG	BG	BG
Medical Res'ch Council (1925)	none	B	B	none	none	none
Suk (1919)	B	insuf.	B	B	B	B
Unglaube (1924)	BG	M[1]	BG	BG	BG	BG
Wallis (1931)	BG	BG	BG	BG	BG	BG
Wuorinen (1926)	BG	BG	BG	BG	BG	BG
No. of sources of data	15	15	18	14	17	17
No. of graphs:						
Boys	9	7	13	8	12	12
Girls	8	6	11	7	11	11
Mixed groups	6	8	5	6	5	5
Totals	23	21	29	21	28	28

[1]Character of data unsuitable for meaningful separation on sex basis.

[2]Cartwright did not tabulate figures for first and second incisors separately.

with an easily located definition of the term. In many instances the only clue to be found was in an inconspicuous footnote, or in the discussion at the end of the article. In one or two cases the meaning of the term could be determined only by becoming thoroughly familiar with the contents of the entire article.

The manner of recording age, likewise, had to be carefully determined. To illustrate, some authors mean 6½ years when they write "6 years." Some express this by giving the age period, as "6 to 7 years," while others designate age by recording the midpoints of the periods. The age periods themselves vary in length from one report to another, ranging from 3-month intervals to one-year intervals. The definitions of "eruption" and the manner of furnishing the time data are given in Table II.

TABLE II

A list of authors whose publications contain information that can be used for determining the exact location of eruption curves along the time axis.

AUTHOR, *with specification of data used*	DEFINITION OF "ERUPTION"	LENGTH OF AGE INTERVALS (*months*)	AUTHOR'S DESIGNATION OF AGE INTERVALS
Bunting	"erupted or erupting"	6	midpoint
Cattell	"broken through the gums"	6	midpoint
Chérot	"apparition dans la bouche"	12	beginning
Cohen, 1928	"when cusps showed"	12	limits and midpoint
Cohen, 1936	not given, but presumably same as above	12	beginning
Degerböl	any stage of eruption, according to contents of report	3	limits
Ekman	"jeder Zahn, der auch nur zu einem Teil das Zahnfleisch durchbrochen hatte"		
rural children		12	beginning
city children		12	beginning
James & Pitts	"just erupting" and "present"	3	limits
Klein, Palmer & Kramer	"one mm. or more . . . . above gum"	12	beginning (6-7 yr. group = 6¾ yrs.)
Medical Res'ch Council.	"any stage of eruption"	3	midpoint
Suk	"erupted or erupting"	12	beginning
Wallis	"broken through the gums"	12	midpoint
Wuorinen	"gesprengt"	12	beginning

The third difficulty encountered in tackling the problem of chronologic age was that relating to the sex differences in the ages of eruption. Even a cursory survey of published data reveals the existence of much disagreement on this point between various authors. Table I, again, shows that the number of publications containing suitable data on eruption in *both* males and females is relatively small if the selection is confined to statistical material that can be graphed. Therefore, in order to augment the supply of basic data used for computing the average sex differences, the literature was searched for other tabulations which would give the sex differences either directly or indirectly.

Most of this additional material was found in the reports already listed in Table I. Regarding the reference furnished by the Medical Research Council of Great Britain (19), the sex differences were obtained from the tables on teeth "in any stage of eruption," other tables being ignored. But three additional sources of information were located. The data by Gebhart (14) on American-born children of Italian ancestry could be utilized by averaging the values for the right and the left teeth in the two sexes. Similarly, the data by Hellman (15) on Jewish-American boys and girls yielded useful figures when averages were computed from the values on "wealthy" and "poor" children. (Certain details concerning Hellman's material can be obtained only by consulting Gebhart's report.) Finally, an article by Steggerda and Hill (20) furnished carefully compiled statistical material, which could be made available in the same manner as Gebhart's tabulations. Only the data on white children were utilized.

Graphing of available statistical data.

After completing the bibliographic search for usable data and after finishing the preliminary standardization treatment of these data, graphs were constructed for all statistical material that could be reduced successfully to this form. Cumulated percentages of erupted or erupting teeth were represented by the ordinates of the points plotted, while the abscissae represented the time factors involved. When the plotting of points for a series of values for a given tooth was completed, a curve was drawn by the freehand method in such a way as to summarize as accurately as possible the trend suggested by the points. A trend line fitted by this method naturally "smooths out" all minor irregularities. As shown in Table II, the age intervals varied from three to twelve months in the publications. However, it was not found much more difficult to draw trend lines for points indicating 12-month intervals than for those indicating 3 or 6-month intervals. The freehand method of constructing integral curves of best fit was selected because it was felt that existing statistical data have not permitted the development of mathematical equations which describe the variation in tooth

emergence with absolute accuracy. The author is aware of the use of logistic curves of the form

$$Y = \frac{K}{1 + e^{a+bx}}$$

by certain investigators in Europe and the employment of the normal probability curve by Klein, Palmer and Kramer in the United States. There are no reasons for doubting the claims that the mathematical methods just mentioned furnish theoretical values which correspond surprisingly well with actually recorded values. Nevertheless, it still remains desirable to subject these mathematical approaches to critical evaluation. One of the purposes of the present study is to furnish biometricians with factual data with which various theoretically derived distributions can be compared.

Determination of sex differences.

The first step after graphing available numerical data consisted of finding out whether there were any consistent differences between the shapes of the frequency distribution curves obtained for males and females. This was important on account of the limited number of statistical studies published, especially since the usefulness of the graphs derived for mixed groups depended upon the non-existence of appreciable sex differences in variation. The results of this investigation, which was carried out separately for each one of the six teeth, indicated no noteworthy differences in the shapes of the curves for boys and girls. For this reason it was assumed, later, that the standard deviations for the sexes are approximately the same for a given class of teeth if the number of children examined is sufficiently large.

As stated on page 217, in order to compute the mean sex differences in the ages of tooth emergence, data from two principal sources were employed. The graphed material already described was one of the sources. If an author supplied data on eruption in both boys and girls, it was a simple matter to note the age difference between the points where the two "ogive" curves for a given tooth crossed the 50 per cent line. This (median) level was selected for making the determinations because, according to elementary theorems of probability, it is an established fact that such estimates are most reliable when they are based on values obtained from the middle ranges of distribution. Furthermore, as was pointed out in the preceding paragraph, no allowances had to be made for significant differences between the shapes of the curves for males and females. The second source of data on sex differences was furnished by tabulations which could not be reduced to graphic form. These data, and the data from graphs, were utilized for computing the figures shown in Table III.

TABLE III

Sex differences between ages of emergence of the first six permanent teeth and the variability of figures obtained from different sources.

(The values are given in decimals of a year.)

Tooth	Number of Sources of Data	Range of Age Intervals	Mean Sex Difference According to		
			Tables	*Graphs*	*All Sources, with Standard Error*[1]
Max. M-1	16	0.07–0.33	0.19	0.17	0.18 ± 0.05
Mand. M-1	14	0.09–0.50	0.29	0.25	0.27 ± 0.08
Max. I-1	19	0.13–0.40	0.28	0.26	0.27 ± 0.06
Mand. I-1	15	0.16–0.38	0.30	0.26	0.28 ± 0.07
Max. I-2	19	0.38–0.70	0.46	0.48	0.47 ± 0.11
Mand. I-2	19	0.18–0.56	0.38	0.35	0.36 ± 0.08

[1] $S.E._{mean} = \pm (S.D. / \sqrt{N}) \sqrt{N/(N-1)}$

Table III gives one striking evidence of the variability of values obtained from data in different publications. There is, however, rather good correspondence between the mean values obtained from ungraphed material and those derived from graphed material. On the whole the "experimental errors" appear to be of almost equal magnitude for all six teeth. If the standard errors of the means are studied, one finds relatively little variation between them from one tooth to another. That for the maxillary second incisor is an exception, being 0.11 years, or 39 to 41 days.

The relative numbers of boys and girls in the tabulations for mixed groups were approximately the same, insofar as could be determined. (For certain details of data by Bunting (5) one must consult Bean (1).) In view of this, it was possible to convert the median ages of eruption for such mixed groups into median ages for males and females. Those for girls were obtained by subtracting one half of each established sex difference from the appropriate median age for a mixed group. Those for boys were obtained by adding the halved differences to the original values. In this study the median age of eruption was held to correspond to the point where a given frequency curve crosses the 50 per cent line of the graph.

Establishment of standards for median ages of eruption.

The completion of the preliminary procedures discussed above enabled one to commence the computation of the average median ages of eruption in males and females. By noting the points where the smoothed frequency curves cross the 50 per cent lines of the graphs, the median ages of tooth

emergence had been determined for each tooth in each sex for several groups of children. By eliminating the reports which did not contain an acceptable definition of "eruption," one could base the computations on the best available data. For example, all reports dealing exclusively with "fully erupted" teeth were disregarded. Only the reports listed in Table II were considered, as it was not felt wise to rely here on any statistical material which could not be evaluated *in toto* by an inspection of its graphic forms.

The final stages of this study had to be carried out on the assumption that the reports utilized for summarization were of equal mathematical worth. It was realized, of course, that this was not actually the case, despite the rigid selection of basic material. However, there was no way of evaluating the comparative biometric reliability of each separate item. All one could hope to accomplish was the establishment of averages which would be reasonably free of any serious distortions due to unavoidable "experimental (i.e., observational) errors." One would expect that since there would be a haphazard distribution of the more reliable and the less reliable basic age items along the time axis, the computed midpoint would represent the best possible compromise between them. The extreme values would cancel each other.

The results of these efforts to determine the most likely median ages of tooth emergence are brought together in Table IV. This table, like Table III, gives one a vivid picture of the surprising variability of figures obtained from different sources, although the data deal exclusively with Caucasians living in the northern temperate zone. Yet the standard errors of the averaged median ages show a remarkable degree of uniformity for all six teeth. Apparently there is almost no difference between the reliability of the available data on males and females, although those on males show slightly less variation than those on females. The median ages of tooth emergence are most securely established for the maxillary first incisor, with standard errors of only 0.04 and 0.05 years (i.e., ± 13 to 20 days). Some teeth, like the mandibular first incisor, have a standard error of 0.06 years (i.e., ± 21 to 23 days).

The median ages given in Tables IV and V represent correct values only for such eventually erupting tooth populations as correspond in number exactly or very closely to the child population samples examined. For five out of the six classes of permanent teeth discussed in this report the median age for a tooth population is the same as that for the child population. The maxillary second incisor is an exception to the rule, since about 2 per cent of the children never erupt the tooth. This means that 50 per cent of the teeth destined for eventual emergence will be present as soon as the tooth can be seen in the mouths of only 49 per cent of the children.

The last column of Table IV shows the average median ages after adjustments that make the sex differences correspond to those shown in the last column of Table III. In a few instances the averages computed from the items utilized for Table IV were one or two hundredths of a year more

TABLE IV

Median ages of tooth emergence, computed to nearest hundredth of a year.

Tooth		Number of Median Age Items Averaged	Range of Median Ages	Averaged Median Ages with Standard Errors[1]	Averaged Median Ages Adjusted to Show Established Sex Difference
Max. M-1	♀	10	5.99 – 6.53	6.25 ± 0.06	6.25
	♂	11	6.17 – 6.68	6.43 ± 0.05	6.43
Mand. M-1	♀	10	5.74 – 6.29	5.98 ± 0.06	5.97
	♂	10	6.01 – 6.51	6.23 ± 0.06	6.24
Max. I-1	♀	12	6.92 – 7.48	7.13 ± 0.05	7.13
	♂	14	7.20 – 7.65	7.40 ± 0.04	7.40
Mand. I-1	♀	10	5.98 – 6.68	6.18 ± 0.06	6.17
	♂	11	6.16 – 6.96	6.44 ± 0.06	6.45
Max. I-2	♀	12	7.80 – 8.52	8.11 [2] ± 0.06	8.11
	♂	13	8.37 – 9.00	8.58 [2] ± 0.06	8.58
Mand. I-2	♀	12	6.99 – 7.55	7.23 ± 0.05	7.24
	♂	13	7.34 –7.87	7.61 ± 0.05	7.60

[1] $S.E._{mean} = \pm \left(S.D. / \sqrt{N} \right) \sqrt{N/(N-1)}$

[2] The median ages for the tooth populations destined for eruption are 8.09 and 8.56 years, for males and females, respectively.

or less than those shown in Table III. The amount of source material utilized for the computations summarized in Table III was more than that used for constructing Table IV. Since the sex differences given in the former table can be looked upon as more reliable than those represented by the averages in the latter table, it was felt advisable to make the adjustments shown in the last column of Table IV before proceeding with the determination of the mean ages of tooth eruption.

Summarization of graphed data on variation in eruption.

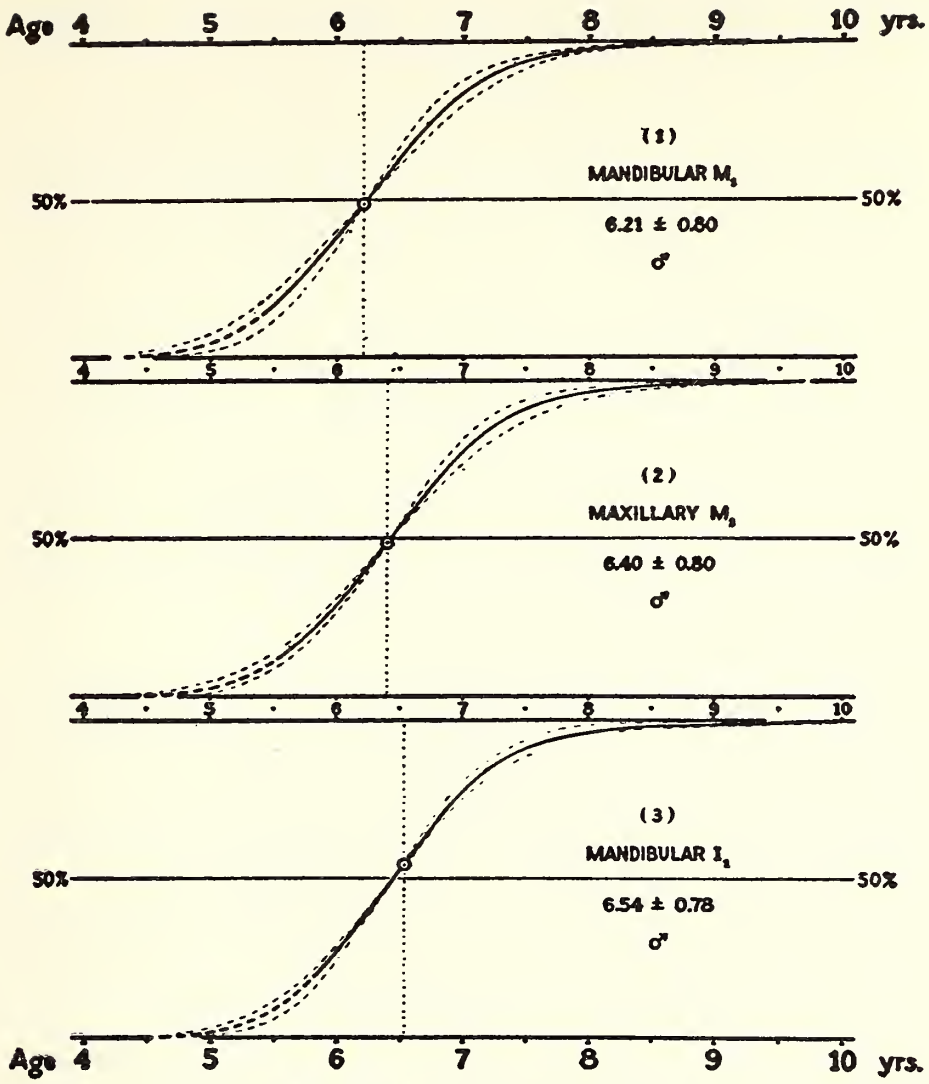
The determination of the mean ages of tooth emergence presented one of the most difficult tasks of the study. To begin with, it could not be as-

sumed that the median ages just computed would necessarily correspond with the mean ages of eruption. Broca (3, 4), the well-known French anthropologist, had objected at length in 1879 to the tendency to assume that the "probable age" of tooth eruption corresponds with the mean age of eruption. In fact, he wrote that he preferred mean age to probable age (called median age by Cournot, Bertillon and others), "because in calculating the latter, each case does not count except by its presence or absence in each half of the series" (i.e., above or below the 50 per cent line). Chérot (8), who utilized Broca's instructions for calculating the means and the medians in his statistical study in 1898, obtained results which indicated clearly the noncorrespondence between the two sets of figures. Without exception, the mean ages of tooth emergence either equalled or exceeded the probable, or median, ages of emergence.

Before the mean ages of tooth emergence could be calculated from the material compiled for the present analysis, it was necessary to summarize the frequency curves obtained previously. All of the curves had been drawn on the same scale on square-ruled, medium-weight drawing paper. By carefully transferring a small number (two, three, or four, as was convenient) of these curves to square-ruled tracing paper in such a manner that the median age points of the curves coincided perfectly, while there was equally accurate superimposition of the upper and lower base lines, it was possible to plot a continuous "average" curve for each small group of curves selected. The median age points were determined, as before, by noting where an individual curve crosses the 50 per cent line. Later, the "average" curves for the small groups were summarized by employing the same technique, care being taken to "weight" each separate curve with a value corresponding to the number of basic items that it represented. By employing this method it was possible to "add" together all cumulative frequency curves for each class of teeth in each sex without recourse to time-consuming mathematical computation.

The process of summarizing the individual frequency curves for each morphological class of teeth brought out some facts of importance. It was mentioned earlier, on page 218, that no appreciable sex differences could be found in the ranges of variation. In the case of every one of the six permanent teeth studied, the shape of the curve obtained by "adding together" all available integral curves for boys was an almost exact duplicate of the corresponding curve obtained for girls. Therefore, in preparing the graphs accompanying this report, the same six cumulative frequency curves were used for both sexes. The only difference between the sexes concerned the location of the standard curves on the abscissa or time axis.

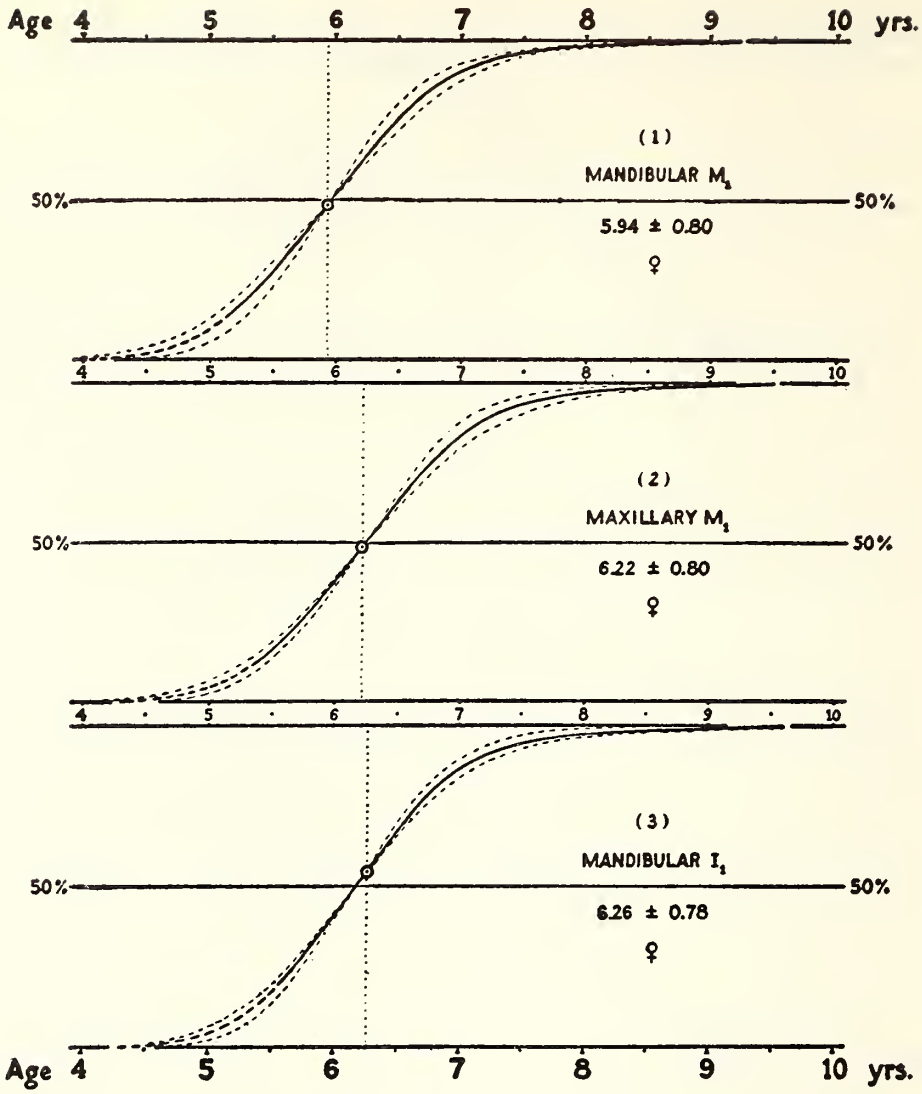
One of the most unexpected results of the analysis was the full revelation of the paucity of reliable data on the emergence of permanent teeth in children under 5½ years of age. Table I gives the reader but incomplete indication of the present dearth of adequate statistical information on the eruption of both first molars and the mandibular first incisor in children who



STANDARDS OF VARIATION IN THE ERUPTION
OF
THE FIRST GROUP OF THREE PERMANENT TEETH
IN
WHITE BOYS OF WESTERN AND NORTHERN EUROPEAN RACIAL STOCKS
PRIMARILY
Fine broken lines indicate limits within which graphs based on best available data can be confined

FIGURE 1

erupt these teeth early. Actually, the number of graphs covering children between 4 and 5½ years of age is very much smaller than the total numbers given at the bottom of Table I. The discrepancy between the number of individual curves that can be "summed up" at each end of the ranges of variation is very marked. Consequently it is not surprising that quite



STANDARDS OF VARIATION IN THE ERUPTION
OF
THE FIRST GROUP OF THREE PERMANENT TEETH
IN
WHITE GIRLS OF WESTERN AND NORTHERN EUROPEAN RACIAL STOCKS
PRIMARILY

Fine broken lines indicate limits within which graphs based on best available data can be confined

FIGURE 2

irregular or even discontinuous curves are obtained by averaging without selection the meager graphic data relating to the age period mentioned above.

In order to overcome the difficulties encountered in trying to plot the average cumulative frequency curves for early eruptors, recourse was had

to an indirect method of attack. It was known that all complete graphs for various classes of teeth showed a high degree of likeness between the two halves of a curve. The curves which represented actually recorded clinical data were very similar to symmetrical logistic curves obtained mathematically; in both cases the curvature in the first half of a given frequency diagram being comparable with the curvature in the second half of the same diagram. There was no reason whatever for believing that the three teeth referred to in the preceding paragraph had integral curves differing in character from those of the other permanent teeth. Therefore, it appeared feasible to determine the probable shapes of the lower sections of their standard curves by utilizing for summarization only such graphic material as appeared suitable for the purpose. The summarizing was limited to the few complete or nearly complete individual curves whose middle and upper sections resembled the corresponding sections of the curves obtained by averaging all available graphic data on the three teeth. Finally, in order to indicate that a certain amount of guesswork was necessary in determining the exact forms of these three curves, heavy broken lines were used in drawing the less securely established lower portions shown in Figures 1 and 2.

The third important point brought out by the summation of available graphic material was the consistent asymmetry of the curves. Although, as stated previously, the curves which result from a plotting of actual observational data are very similar to symmetrical logistic curves, this similarity is by no means as close as certain published analyses would lead one to believe. Furthermore, the degrees of asymmetry of the frequency distributions vary for the different classes of teeth. In the case of each of the six permanent teeth studied the proportion of curve above the 50 per cent line is noticeably more than that below the same level. Concomitantly the curvatures above the points of inflection are invariably less sharp than those below, as can be seen by studying Figures 1, 2, 3 and 4.

Another point brought out in the course of this comparative study concerns the remarkable degree of similarity between the shapes of individual graphic curves drawn for the same tooth. It is to be remembered that the individual curves represent data collected on widely-scattered white population groups in the northern temperate zone at different periods of time. The seventeen authors listed in Table I represent eight different countries. The eighteen reports produced by them appeared at irregular intervals between the years 1857 and 1940. Notwithstanding the wide divergence between the various sources of data, the individual curves for a given tooth vary rather little from each other in form.

This fact can be demonstrated visually by drawing for each tooth the limits of a zone which could contain the separate curves if these were superimposed so that their median age points (or points of inflection) coincided. The fine broken lines on each side of the curves shown in Figures 1, 2, 3

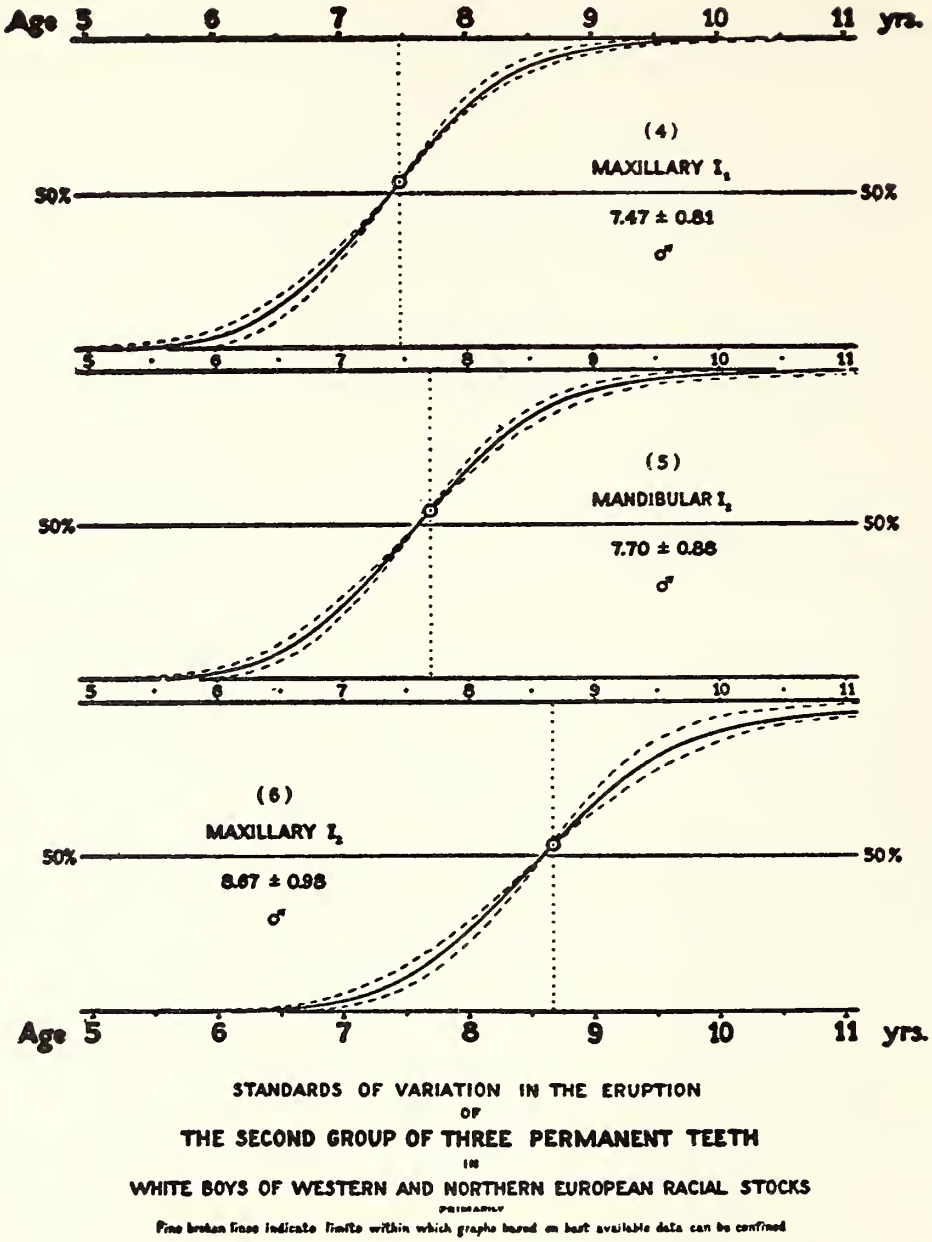
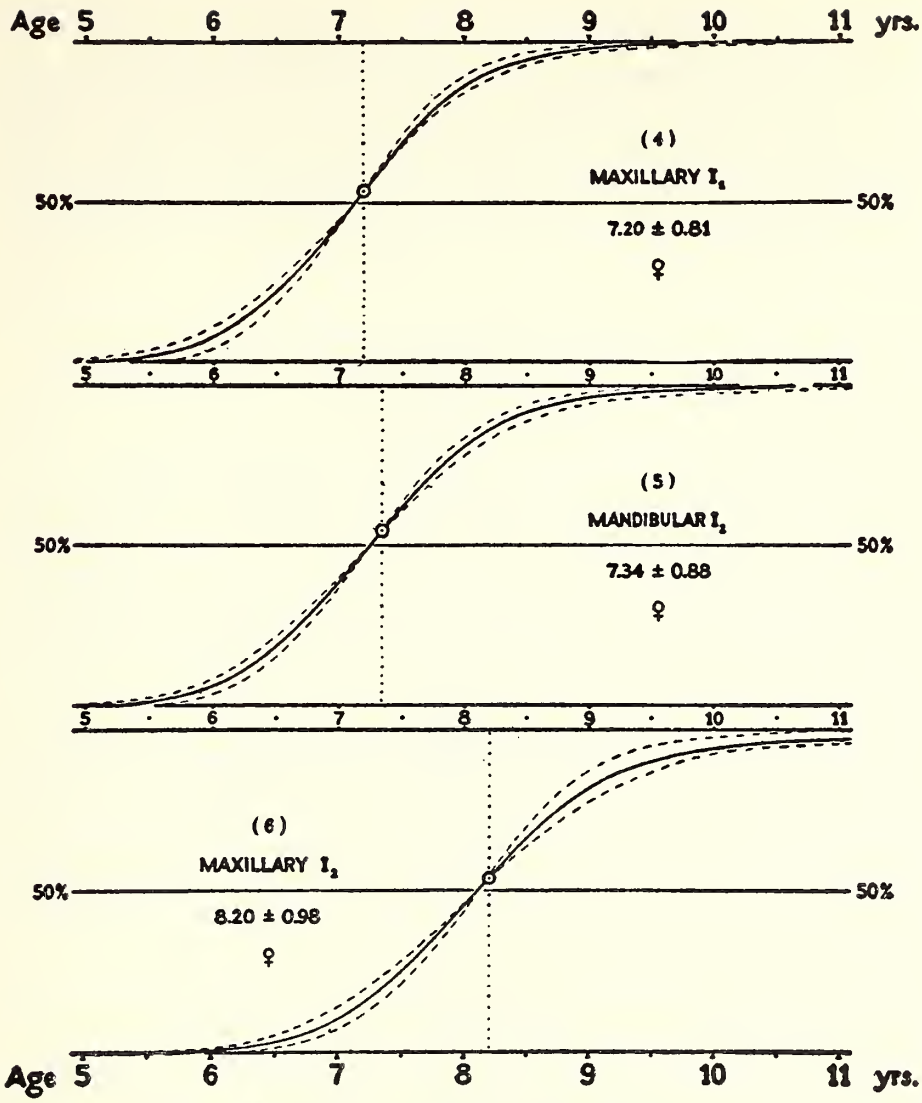


FIGURE 3

and 4 indicate such limits.[1] The zones shown in the diagrams are very narrow for some teeth, among which the mandibular first and second in-

[1]The graphs representing Bunting's data on the three teeth shown in Figures 1 and 2 were omitted in drawing the zone limits. These graphs differed so markedly from the general pattern of all other graphs that they were suspected of representing statistically questionable observations.



STANDARDS OF VARIATION IN THE ERUPTION
OF
THE SECOND GROUP OF THREE PERMANENT TEETH
IN
WHITE GIRLS OF WESTERN AND NORTHERN EUROPEAN RACIAL STOCKS
PRIMARILY
Fine broken lines indicate limits within which graphs based on best available data can be confined

FIGURE 4

cisors are the most conspicuous. The greatest disagreement regarding the shape of the eruption curve centers around the maxillary second incisor.

The fifth interesting by-product of the curve summarization process has to do with the same tooth, to wit, the maxillary second incisor. Figures 3 and 4 do not show the cumulative frequency curve for this tooth reaching

the 100 per cent line, as do all of the other standard curves. This failure is not due entirely to an insufficiency of space for drawing the diagram. The massed statistical evidence indicates beyond any doubt that there is fairly frequent agenesis and nonemergence of the organ in question. The curve that represents an averaging of 28 individual items levels off at, or slightly above, the 98 per cent line. Thus about 2 per cent of white children of western and northern European racial stocks fail to either develop or erupt the tooth.

TABLE V

Median and mean ages of tooth emergence, with computed[1] *standard deviations.*

(The values are expressed decimally, in terms of years.)

Tooth		Median Ages	Mean Ages	Standard Deviations *(for both sexes)*
Max. M-1	♀	6.25	6.22 [2]	0.80 [3]
	♂	6.43	6.40 [2]	
Mand. M-1	♀	5.97	5.94 [2]	0.80 [3]
	♂	6.24	6.21 [2]	
Max. I-1	♀	7.13	7.20	0.81
	♂	7.40	7.47	
Mand. I-1	♀	6.17	6.26	0.78
	♂	6.45	6.54	
Max. I-2	♀	8.11 [4]	8.20	0.98
	♂	8.58 [5]	8.67	
Mand. I-2	♀	7.24	7.34	0.88
	♂	7.60	7.70	

[1]Computation is specified to indicate that the standard deviations were not derived by using probability paper, or other indirect methods.

[2]Probably somewhat too low.

[3]Probably one or two hundredths of a year too high.

[4]Median age for tooth population destined for eventual emergence is 8.09 years.

[5]Median age for tooth population is 8.56 years.

Establishment of standards for mean ages of eruption.

The completion of the tasks described above made it possible, finally, to calculate the mean ages and standard deviations of tooth emergence. The system of procedure developed by Broca was used. The numerical data needed were obtained from large-scale diagrams showing the standard curves for each tooth. The age classes employed were on the basis of tenths of a year; the hypothetical number of individuals considered was 1,000 in all cases except one. The exception concerned the maxillary second incisor, for which tooth the hypothetical number employed was 980.[2]

The means and their standard deviations are given in the diagrams (Figures 1, 2, 3 and 4) and in Table V, which brings these data together with the median ages already computed. The mean ages of eruption are seen to be generally higher than the median ages. In the case of two teeth the difference is as much as one tenth of a year. As was mentioned earlier, Chérot found similar differences between mean and "probable" ages.

The first molar figures on means and medians form an exception to the general rule. The mean ages of eruption for these teeth are 0.03 of a year lower than the median ages. It is quite likely that this exceptional sequence is due to the insufficient quantity of reliable data that could be obtained for determining the exact shapes of the lower parts of the cumulative frequency curves for these teeth. Future investigations may show that these curves should be somewhat steeper than the ones shown in Figures 1 and 2. In that case the mean age points would shift slightly to the right (perhaps even above the 50 per cent line), while the standard deviations would come out less than 0.80 of a year.

Summary

1. Lack of summarized data on the eruption of permanent teeth has forced anthropologists and students of child development to contend with a number of disharmonious tabulations. The degrees of agreement and disagreement between various publications have been unknown.

2. This report furnishes a synthesis of the best available data on the emergence of the first six permanent teeth in boys and girls living in the northern temperate zone. The material analyzed and summarized represents western and northern European ethnic groups almost exclusively.

[2]Due to the fact that a few individuals in any large population group fail to develop one or more of their permanent teeth, no frequency curve should actually reach the 100 per cent level. With the exception of the maxillary second incisor tooth the percentages of agenesis and nonemergence are so small for the other five classes of teeth discussed in this paper that no serious errors result from ignoring them.

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CRITICAL COMMENTS ON APPEARANCE AND FUSION OF EPIPHYSEAL CENTERS

The reason for republishing together here the papers of Stevenson and Flecker is explained in the Foreword. The main criticism of Stevenson's work was published by one of the editors (T.D.S.) under the title "Sequence of epiphyseal union, third molar eruption and suture closure in Eskimos and American Indians" (Am. J. Phys. Anthrop., vol. 19, no. 3, 1934, pp. 433-452). Flecker's findings regarding the sequence of epiphyseal union agree with those of Stewart and hence support the latter's criticism of Stevenson.

Among the skeletons examined by Stevenson was at least one with a sequence of epiphyseal union that has not been duplicated by others (his no. 633). This raises the possibility that abnormal sequences of union may be encountered in the skeletal remains of present-day populations presented for identification. For this reason it is well to check the total pattern of union in each skeleton to see if it follows the usual order before proceeding to estimate age.

Readers should also consult a paper by F. Vandervael (S.A.S., Bologna, no. 25-26, 1952) in which he reports the ages of union for 7 epiphyses as observed in the skeletons of 225 American white soldiers of World War II.

Flecker's paper is not confined to epiphyseal union, but covers also the dates of appearance of the ossification centers. This is not a subject that has much bearing on skeletal identification unless there are tissues present to hold the developing centers in place. For comparative data on this subject, the reader should consult the following:

Hill, Alfred H.—Fetal age assessment by centers of ossification. Am. J. Phys. Anthrop., vol. 24, 1939, pp. 251-272.

Francis, Carl C. and Peter P. Werle—The appearance of centers of ossification from birth to 5 years. Ibid., vol. 24, 1939, pp. 273-299 (with the assistance of Alton Behm).

It will be apparent to the reader that all of the authors mentioned disagree to some extent on the ages to be assigned to the physiological events with which they are dealing. Probably this is due to differences in the groups studied and ultimately reflects environmental factors in the broad sense, but particularly social background.

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AGE ORDER OF EPIPHYSEAL UNION IN MAN[1]

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Introduction

The phenomenon of diaphyso-epiphyseal union has long occupied a position of dominating importance in the consideration of gross skeletal metamorphosis associated with the question of age. The time and sequence of union between the various epiphyses and their respective diaphyses has not only been the chief, but in many cases the only, guide of anatomists, archeologists, medico-legal experts, and others in their efforts to estimate the ages of individuals upon the basis of skeletal findings. In spite of the fact that complete union of all the epiphyses in early life naturally restricts the application of this particular type of osteological evidence to skeletons of adolescent or young adult individuals, leaving the determination of age in later life periods dependent upon more generalized though not less definite observations (Todd, '20), still the time and sequence of epiphyseal union will always constitute a prominent factor in age determination within the natural limits just mentioned.

[1]This article is the substance of a thesis which was accepted for the degree of M.A. in Medicine, Western Reserve University, June 1923.

TABLE 1. Ages assigned by various authorities for union of epiphyses.

Epiphyses \ Authority	Bryce ('11)	Dixon ('12)	Dwight ('11)	Gegenbaur ('92)	Henle ('71)	rause ('09)	Lewis ('18)	Poirier ('11)	Terry ('21)	Testut ('21)	Thompson ('21)	Earliest	Latest	Difference
Humerus:														
Head	20-22	20-25	20	--	--	22	20	20-25	20	20-25	25	20	25	5 yrs.
Distal Ext.	17	17	15	18	15	16-17	17	16-17	17	16-18	16-17	15	18	3 "
Med. Epicond.	18	18	--	--	16	18	18	16-17	17	17-19	18-19	16	19	3 "
Radius:														
Proximal	17-19	18	16	17	16	16-17	17-18	16-19	17	16-20	18-20	16	20	4 "
Distal	18-20	21-25	19-20	20	19-20	20-21	20	20-25	20	20-25	20-25	18	25	7 "
Ulna:														
Proximal	17-19	17	16	17	15-16	16-17	16	20-21	16-17	16-20	16	15	21	6 "
Distal	18-20	20	18	20	20	20-21	20	22-24	18-20	20-25	20-23	18	25	7 "
Femur:														
Head	18-19	18-20	18	20-25	20	17-19	Puberty to 20	18-22	19	18	18-20	18	25	7 "
Lsr. Trochant.	16	18	19	20-25	--	17-19		18-22	17	18	18	17	25	8 "
Gtr. Trochant.	17	18	19	20-25	--	17-19		18-22	18	16-18	18-19	17	25	8 "
Distal Ext.	20	23-24	20	23	--	19-20		22-24	20	20-22	20-22	19	24	5 "
Tibia:														
Proximal	19-24	21	19-20	--	18-25	19	20	18-24	20-25	18-20	20-24	18	25	7 "
Distal	17-19	17-18	18	--	18-25	17-18	18	16-18	18	16-18	18	17	25	8 "
Fibula:														
Proximal	22-24	22-24	20	--	19-25	19	25	22-23	22	19-22	19	19	25	6 "
Distal	20-22	20	18-19	--	19-25	17-18	20	20-22	20	18-19	19	17	25	8 "
Scapula:														
Coracoid	Puberty	17	14-15	16-18	14-15	16-18	15	20-25	15	14-16	15-17	14	25	11 "
Acromion	22-25	22-25	18-19	--	16-17	19-21	--	20-25	20	17-18	25	16	25	9 "
Inf. Angle	25	22-24	20	--	20	21-22	25	--	25	22-25	20-25	20	25	5 "
Vert. Margin	25	22-24	20	--	21-22	21-22	25	25-28	25	20-24	20-25	20	28	8 "
Innominate:														
Primary Elements	Puberty	17-18	15	Puberty	Puberty	16-18	Puberty	15-20	18-20	15-16	16	15	20	5 "
Ischial Tuber.	18-25	18-20	20	24	22-24	17-24	20-25	18-20	20	15-20	20-25	15	25	10 "
Iliac Crest	18-25	18-20	20	24	22-24	17-24	20-25	20-25	20	24-25	22-25	17	25	8 "
Ramal Epiphysis	--	--	--	--	--	--	--	--	--	--	--			
Clavicle	25	25	18	--	18	20-22	25	25	25	22-25	25	18	25	7 "

Without entering into a detailed resumé of the existing views on the subject, it is enough to note that our present conceptions of the time and sequence of epiphyseal union are apparently based almost entirely upon a few chance and wholly uncorrelated observations. A tabulated analysis of the data presented in the current text books of Anatomy (Table 1) for instance, reveals a most striking divergency of opinion as to the actual time of union of the various epiphyses. In this connection, Elliot Smith ('12), when confronted with the task of assigning ages to some of the Royal Mummies of Ancient Egypt, made a similar survey of the existing knowledge on the subject and concluded that "in the present state of our knowledge, it would be rash and altogether unjustifiable to give in figures the precise age of a skeleton without making the reservation that it might be several years older or younger than the estimate." Similar difficulties were apparently met with, though less clearly stated, by F. Wood Jones ('10) in his study of the age and sex of a large number of human remains from lower Nubia.

The extent to which the venerable hand of tradition still controls our teaching on the subject of the time element in epiphyseal union is seen in the frequency with which expressions found in the earliest editions of well known texts are retained practically verbatim in some of the latest editions of these same works. Very rarely indeed do we find a reviser of a text book taking exception to archaic ideas of a former day and inserting, as in the case of Dwight ('11), contrary though positive evidence based upon his own scanty observations. In the more recent anatomical literature outside of text books the writer also fails to find any reference to an adequate studyof the exact ages at which the various epiphyses unite. In fact, the present practice of anatomical text books of dealing with the subject in only the most general terms certainly leaves the enquirer with the impression that epiphyseal behavior is so erratic in nature as to defy its reduction to formula.

In view of the obvious deficiency of our present knowledge along this line, and the attending difficulties even in the hands of the most competent in the way of applying the present confusing data to the actual determination of age of historical or otherwise valuable skeletal material, it seems highly desirable to review our knowledge of the age and sequence of union of the various epiphyses and to establish, if possible, a more authoritative basis for the determination of age by reference to epiphyseal union than has hitherto been done.

The present communication results from an effort to revise our knowledge of the time and sequence of epiphyseal union. The facts herewith

presented are derived from a detailed study of actually uniting epiphyses in a series of skeletons of definitely known age. This age-known material arranges itself with sufficient evenness throughout the whole period of epiphyseal activity to make possible an accurate determination of (1) the age of the union of the individual epiphyses (2) the sequence of union of the different epiphyses, and (3) the actual duration of the period of epiphyseal union as a whole.

Many interesting questions of varying importance naturally arise during an investigation of this kind. Most of these, largely because of their rather speculative nature, are rigidly excluded from this paper in which the writer purposes to confine himself almost exclusively to facts bearing directly upon the time and sequence of epiphyseal union in the human body. Certain impressions concerning the fundamental nature of the phenomenon of epiphyseal union in general and the alleged relationship between epiphyseal union and growth in particular, however, seem inevitable from the evidence at hand and will be touched upon in appropriate sections. Bare mention of observations on the behavior of epiphyses in primate forms other than Man must be made in the discussion first of the sequence of epiphyseal union, and secondly in dealing with the fundamental nature of the phenomenon of epiphyseal union.

The constancy of the age factors involved, not only in the process of epiphsyeal union as a whole but in the union of the large majority of individual epiphyses as well, will be repeatedly emphasized throughout this paper. Although, for the sake of completeness, the more erratic epiphyses of the scapula and os innominatum will also be described, yet the behavior of these is clearly the exception to the general rule and the reader is warned against allowing their relatively variable behavior to detract his attention from the main premise of constancy and regularity, as demonstrated in the case of all the more important epiphyses of the body.

As a further word of introduction it is to be mentioned that this study represents an integral part of a series of studies on age changes in the skeleton being carried on in the anatomical laboratory of Western Reserve University. Such matters as the general scope of these interesting studies, as well as the questions of age records, uniform routine preparation of skeletal material with the particular end of age studies in view, and other pertinent subjects are treated somewhat in detail in Professor Todd's initial publication on the subject (*op. cit.* pp 285–292),

and apply equally well to the material used in the present study on the epiphyses.

Material

The authority of a study such as this depends largely upon three factors; (1) the *number* of complete skeletons of suitable age period available, (2) the undoubted *normality* of the material used, and (3) the question as to whether or not definite *data as to the age* of the skeletons is available.

Of the approximately 1,000 complete skeletons now filed in the Western Reserve collection, 128 fulfilled the first of the above mentioned conditions, being within the age period between 15 and 28 years. Of this number failure on the part of 18 to conform to the required conditions regarding unquestioned normality and definite age data reduced the number to 110. The one exception to this rigid rejection of skeletons for which it was not possible to produce unimpeachable evidence as to age is the one in the fifteen year column (of the table below) about which there is conflicting evidence as to whether the correct age is fourteen or fifteen years. This body is included solely because of the very valuable evidence which it presents concerning the *sequence* of epiphyseal union.

Table 2. Number, stock, sex, and age of skeletons used in this study.

		Period I					Period II									Totals
Age / Stock		15	16	17	18	19	20	21	22	23	24	25	26	27	28	
White	M.				2	2	3	2	4	4	4	5	4	7	2	39
	F.				2	1	1			1		3		1	1	10 (49)
Colored	M.			1	5	3	5	4	9	7	4	1	4	3	5	51
	F.	1		2	1		2				2	2				10 (61)
Totals		1		3	10	6	11	6	13	12	10	11	8	11	8	110

On account of the existing uncertainty as to its exact age it does not appear either in the argument or graphs dealing with the *time* of epiphyseal union. Table 2 shows how this total number is divided as to human stock, sex, and age. The number of Whites and Negroes is practically the same, while the males greatly predominate in both races. The heavy vertical line divides the total age period into two shorter periods. The first of these, up to and including the twentieth year is characterized by the completion of all epiphyseal union in the so called long bones (v. also Fig. 11 and Plate I), and will be considered the true epiphyseal period; while the second period, from the twenty-first to the twenty-eighth years, witnesses the more delayed union of

certain other constantly present epiphyses, notably those of the scapula, os innominatum, and clavicle.

Although this study is primarily concerned with the time and sequence of epiphyseal union in the case of the human body, yet studies on a larger number of other mammalian forms to be published later show that the *sequence* of union is apparently constant throughout the entire range of land mammals. Where a rather critical gap in the definitely age-known human material in the earliest stage of epiphyseal activity made the procedure necessary three skeletons of higher Primates other than Man were selected to show intermediary stages. Use of this material was made only after it had been clearly demonstrated to the writer that in sequence of epiphyseal union anthropoid material is absolutely identical with the human. As in the case of the 14-15 year specimen mentioned above, this outside material is concerned only in the case of the *sequence* of union, and will not enter into the discussion of the time of epiphyseal union.

Stages and Criteria of Union

Before beginning a specific investigation of the time and order of union of the various epiphyses, a preliminary study of the phenomenon as a whole was made in order to acquire a general appreciation of the progressive changes taking place at the epiphyso-diaphyseal junction. Through such a study it is possible to recognize four more or less distinct phases of epiphyseal union, each presenting characteristic and constant features. (1) In the first, or stage of *no union*, the clearly evident hiatus between the epiphysis and diaphysis, as well as the characteristic saw-tooth-like external margins of the approximated diaphyseal and epiphyseal surfaces, present unmistakable evidence of the condition of nonunion. In this stage the epiphysis has not infrequently become entirely separated from the diaphysis in the process of maceration, leaving a billowy surface which is characteristic of this stage; a point to be noted in connection with the less frequent cases of epiphyses becoming forcibly separated at a later stage when partial union has taken place. (2) In the second, or stage of *beginning union*, a tendency is evident for the distinct superficial hiatus between epiphysis and diaphysis to be replaced by a line. The saw-tooth character of the approaching margins is gradually lost through the deposition of finely granular new bone in the depressions. Quite as characteristic of this stage is an occasional bridging over or knitting together of the two margins, an external manifestation of the process of obliteration of the

space between the diaphysis and its epiphysis. This process of bridging over and progressive obliteration of the epiphyseal line becomes increasingly conspicuous from this stage on. Diaphyseal and epiphyseal surfaces resulting from the occasional complete separation of the epiphysis at this stage are not difficult to distinguish from those of the preceding stage when the filling in of the depressions by new bone deposition and the resultant smoothing out of the former rugged surface is noted. (3) The third, or stage of *recent* union, is the least definite of the four and offers at times some difficulty even to the most experienced observer. This stage is characterized chiefly by the retention of a fine line of demarcation, although the active process of bony union is plainly over. This line, which varies much in distinctness on different bones and in different skeletons, can be seen best in freshly macerated skeletons, when it usually, though not always, has a faintly reddish color. The line in question must be clearly distinguished from the "epiphyseal scar" which is occasionally met with in the fourth stage, and less frequently throughout life. (4) The fourth, or stage of *complete union*, represents the completion of the process of union and usually offers no difficulties in its recognition. In a certain small percentage of cases there may be a faint epiphyseal line persisting throughout life. Care must be taken in the case of such lines, however, especially in the case of the distal end of the femur and the proimal end of the tibia not to mistake a relatively conspicuous line of capsular attachment for the epiphysial line itself.

Although four distinct stages of epiphyseal union have been noted above, and all four stages will be regularly indicated in the charts and diagrams which follow, still it must not be considered that they represent differences of equal importance. Stages (1) and (2) represent but slightly different phases of an as yet ununited condition, while stages (3) and (4) similarly represent only slightly different phases of total union of an epiphysis. The difference between nonunion and union is distinct and significant, that between the respective minor phases of each is less distinct and less significant. The essential point to note, therefore, in the union of any particular epiphysis as it is being followed through a series of individuals of increasing age, is the change from the first of these major conditions, with its two qualifying phases, to the second major condition, of which two more or less distinct phases are also recognizable. And it is the time at which this significant transition between the major stages of absolute nonunion and complete union

respectively takes place that determines the actual age of union of the epiphysis in question.

Having in mind these different stages of epiphyseal union and their relative significance, the behavior through successive age periods of twenty-eight distinct epiphyses of ten bones of the human skeleton will now be briefly described.

Age of Union of Various Epiphyses

Chronological sequence in any series of bodily changes is most naturally represented in diagramatic form. Although the changes taking place in the various epiphyses of each bone will be briefly described under the respective headings of this section, yet the gist of the present study will most easily be presented in the accompanying graphs, and the most satisfactory conception of the time and sequence of union of the epiphyses in question can best be obtained through a careful study of these diagrams as they appear in the text.

Definite evidence for the date of union of an epiphysis rests upon three principles. The series of skeletons being arranged in age sequence; (1) before a certain age no skeleton shows union of the epiphysis in question; (2) after a certain age every skeleton shows union of that particular epiphysis; (3) between these age limits lies the period during which union is actually taking place.

At this juncture, as an aid in readily utilizing the first two of the above factors in the determination of the third, attention is called to the significance of the dotted line in the figures that follow. This line running horizontally across each diagram, separates an area representing nonunited epiphyses below from one representing united epiphyses above. The slight fluctuations within these two areas indicate the qualifying phases (v. supra) of nonunion and union respectively and are of secondary importance only. The important point to notice is the particular age period during which the graph of the uniting epiphysis crosses the dotted line from below upward. This is the period during which union is actually taking place.

HUMERUS

(*Fig. 1.*)

In the humerus a relatively late fusion of several separate centers of ossification results in the appearance of three well defined and constant epiphyses; those of the distal extremity, medial epicondyle, and head. Of these three epiphyses, two show indications of very early union, in

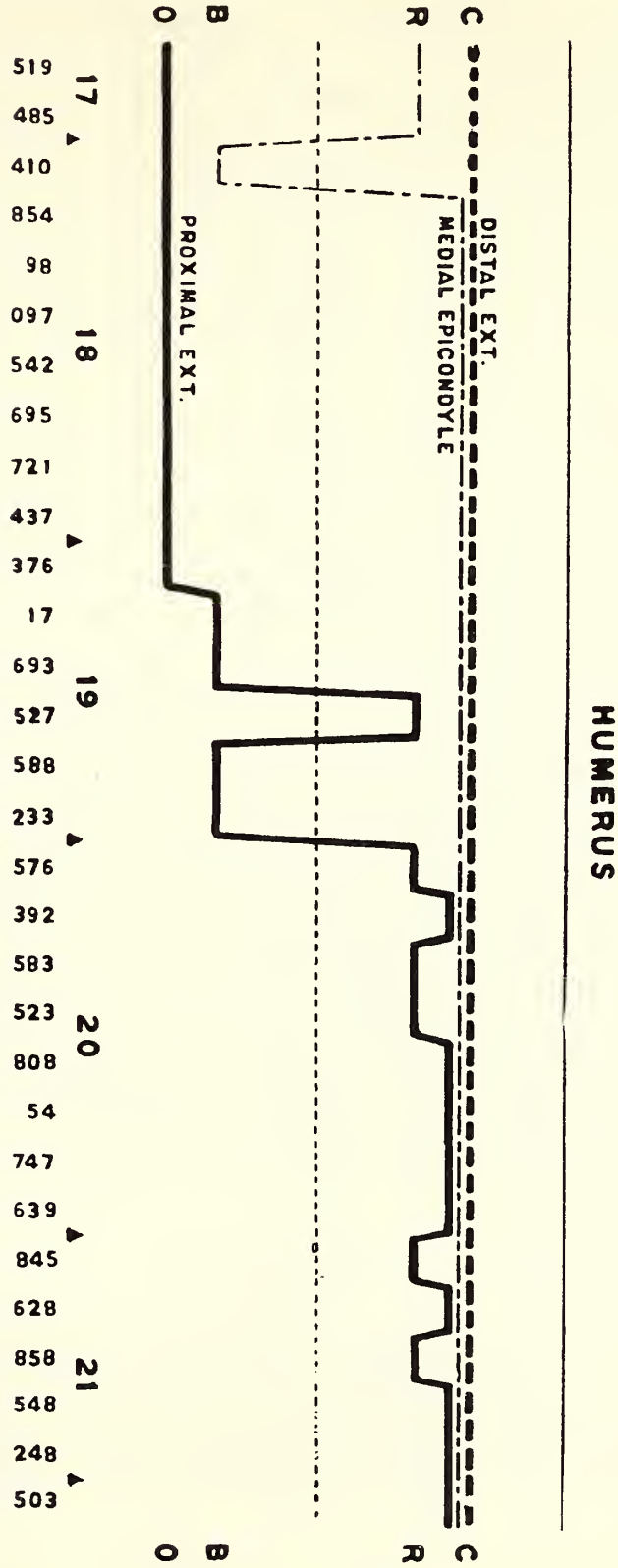

FIG. 1. Age of union of epiphyses of humerus.

fact before the seventeen year age period at which the present series of age-known material begins. Evidence as to the time of union of the epiphysis of the distal extremity, however, is to be found in skeleton No. 633 (the fourteen-fifteen year old skeleton which is not included in the age-known series for reasons assigned above). In it, as shown in Plate II, the distal epiphysis is already completely united. For the present therefore one must tentatively assign the union of this epiphysis at the distal extremity of the humerus at fourteen to fifteen years. Of the epiphyses included in the present study this is the earliest to unite, and it will receive later treatment in the discussion of the sequence of epiphyseal union.

The actual age of union of the medial epicondyle is also earlier than seventeen years. Complete absence of union of the epiphysis in the case of skeleton No. 633, however, places the event after the fourteen-fifteen year period, while the recent union in the case of the seventeen year old skeletons indicates that union takes place at about sixteen years.

For the head of the humerus, as for practically all the remaining epiphyses of the body, we are able to assign definite limits to the date of union. No skeleton under nineteen years shows even commencing union of the humeral head. After the age of nineteen, on the other hand, this epiphysis is already united in every skeleton. It follows that the nineteenth year is the period during which actual union of this particular epiphysis takes place. Or, stating the matter in a slightly different way, union of the head of the humerus indicates that the individual under observation is twenty or more years old. The head of the humerus, it may be mentioned here, is the last to unite of the epiphyses under consideration, and we will have occasion to refer to it again in the discussion of the sequence of epiphyseal union.

In summary, the ages at which the various epiphyses of the humerus will be found united are; the distal extremity at fifteen years (tentative), the medial epicondyle at sixteen years (tentative), and the head at twenty years.

RADIUS AND ULNA

(*Figs. 2 & 3.*)

The epiphyses of the radius and ulna may be conveniently treated together. It is evident that the proximal epiphyses of both these bones unite considerably earlier than those of their distal extremities. The proximal scalelike epiphysis capping the olecranon process of the ulna represents what may be termed an extra-articular epiphysis, a

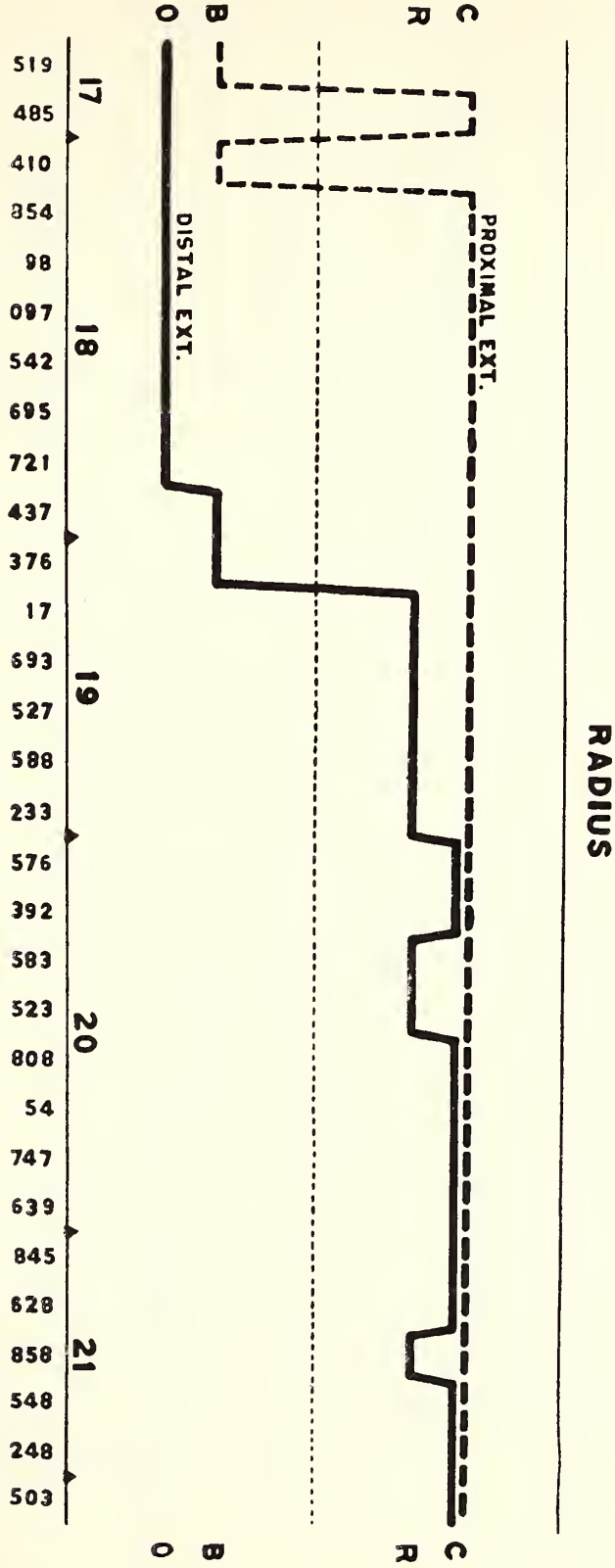

FIG. 2. Age of union of epiphyses of radius.

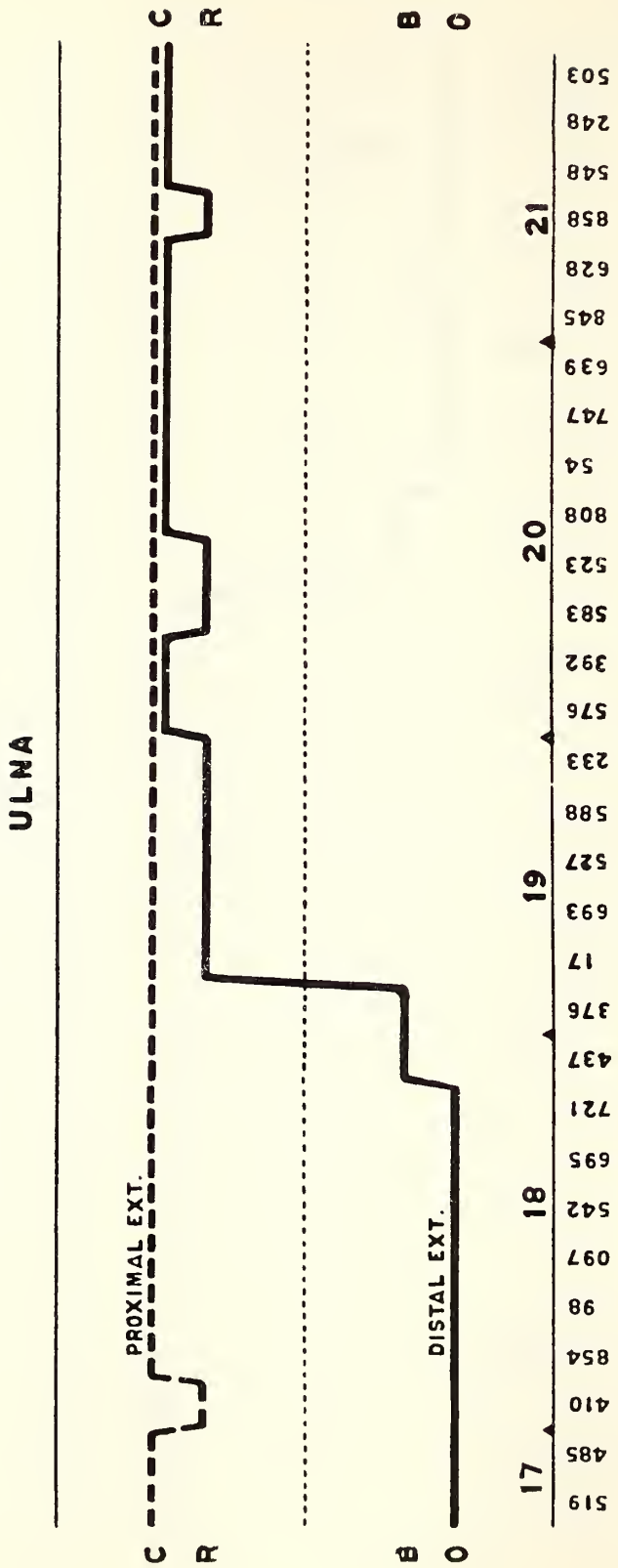

FIG. 3. Age of union of epiphyses of ulna.

type which, as will be shown subsequently, is less constant in behavior and hence less valuable as an age indicator than the ordinary epiphysis entering into joint formations. Union of the proximal ulnar epiphysis occurs somewhat earlier than the seventeenth year, probably at about the sixteenth, and the actual time of this union, on the same grounds as in the case of the medial epicondyle of the humerus cited above, must be tentatively stated as sixteen-seventeen years.

The head of the radius, more constant in its behavior than the proximal epiphysis of the ulna just described, does not show consistent union before the beginning of the eighteen-year period. Without exception, on the other hand, this epiphysis is firmly united in all cases over eighteen years of age. It may be stated therefore, that the eighteenth year is the period of union of the epiphysis of the head of the radius.

The close parallelism in the behavior of the distal epiphyses of the radius and ulna is noteworthy. The graphs of these indicate that union with their respective diaphyses takes place in the early part of the nineteenth year.

The ages at which the epiphyses of the radius and ulna unite are the following: sixteen-seventeen years for the proximal epiphysis of the ulna, eighteen years for the head of the radius, and nineteen years for the distal extremities of both bones.

FEMUR
(*Fig. 4.*)

The epiphyses of the femur comprise the lesser and greater trochanters, the head and the distal extremity. All of these are remarkably constant in date of union and are accordingly useful indicators of age. Contrary to what one would expect from conventional statements, the two trochanters and the head unite practically simultaneously, although the lesser trochanter exhibits a tendency to unite slightly earlier than the other two proximal epiphyses of this bone. The time of union of all the proximal femoral epiphyses is the early part of the eighteenth year.

The evidence is equally clear that union of the distal epiphysis of the femur takes place approximately a year later, namely, in the early part of the nineteenth year. The accelerated union of this one epiphysis in the case of skeleton No. 721 is an extreme example of individual variation in the case of a single epiphysis of the body, for with this one exception all the remaining epiphyses of this particular skeleton are found to conform to the usual eighteen-year type.

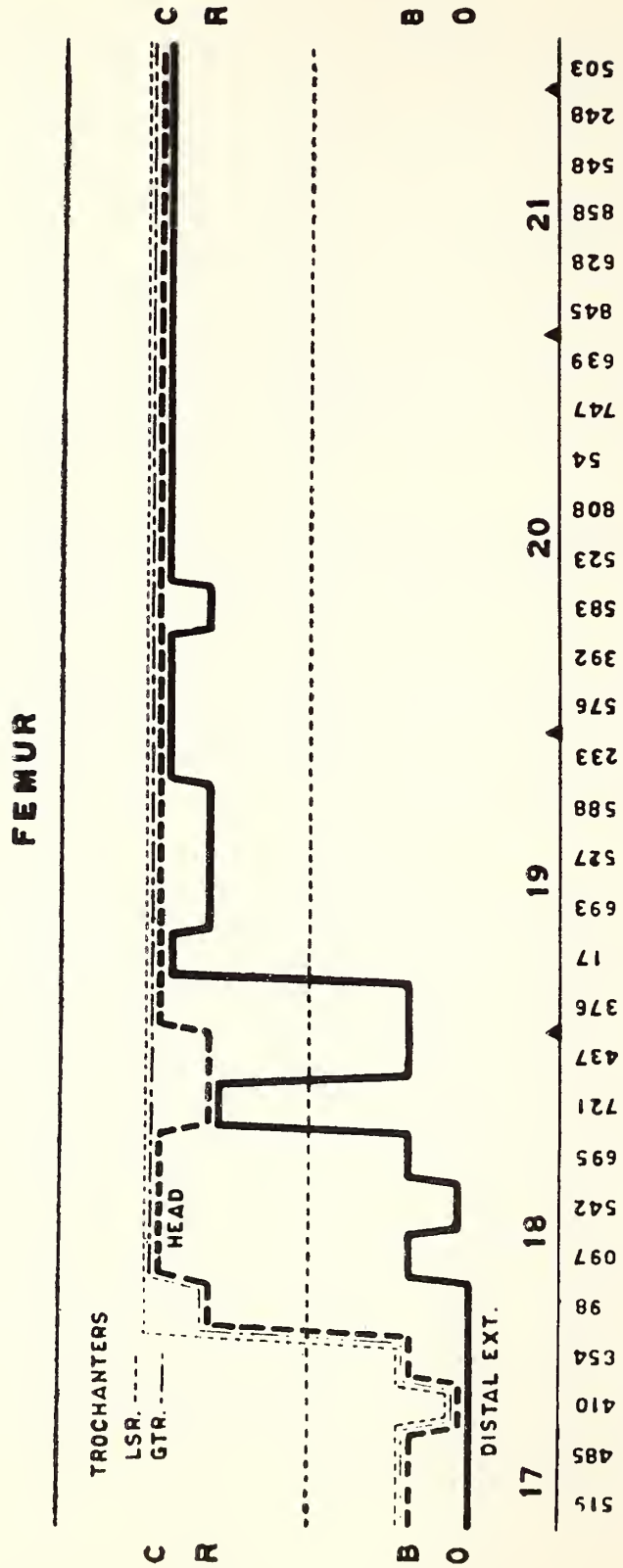

FIG. 4. Age of union of epiphyses of femur.

For the epiphyses of the femur, therefore, the age of eighteen years is the time of union for the two trochanters and the head, while nineteen years is the age of union of the distal extremity.

TIBIA AND FIBULA
(*Figs. 5 & 6.*)

The epiphyses of the tibia and fibula, like those of the radius and ulna, may conveniently be considered together. Contrasted with the definite behavior of the radial and ulnar epiphyses, however, these four epiphyses of the tibia and fibula show a relatively large degree of individual variation, and are on the whole the least reliable as age indicators of all the long bone epiphyses.

The distal epiphyses are more constant than those of the proximal ends of the bones in the date of their union. Although there is evidence in some skeletons (v. No. 98) that the distal epiphysis of the tibia may unite a little before that of the fibula, yet the eighteenth year is clearly the period during which both these epiphyses unite.

The proximal epiphyses, especially in the fibula, show a considerable degree of individual variation. No skeleton exhibits union of either of these before the early part of the eighteenth year, and it is not until practically a year later that union is complete in every skeleton in the series. Although this period of fluctuation is not of considerable duration, and is certainly much shorter than that usually ascribed to even the most constant epiphyses, still it is relatively long when compared with the more definite behavior that characterizes the other long bone epiphyses already described.

With the exception of the tibial and fibular epiphyses, particularly that of the proximal end of the fibula, the long bone epiphyses described in the preceding paragraphs of this section are distinguished by a characteristic constancy of behavior which makes them of primary importance in age determination. There follows a group of bones—the scapula, os innominatum, ribs, and clavicle—most of the epiphyses of which are of the marginal type, some of them probably vestigial in nature (v. infra), and all of them rather variable in date of union. As indicators of age, therefore, they are to be considered distinctly secondary in importance to the epiphyses of the long bones.

Certain skeletal elements which strictly cannot be called epiphyses are also associated with these bones. These—the coracoid and acromion of the scapula, and the three primary elements of the innominate bone in particular—exhibit such constancy in their dates of union, and as a

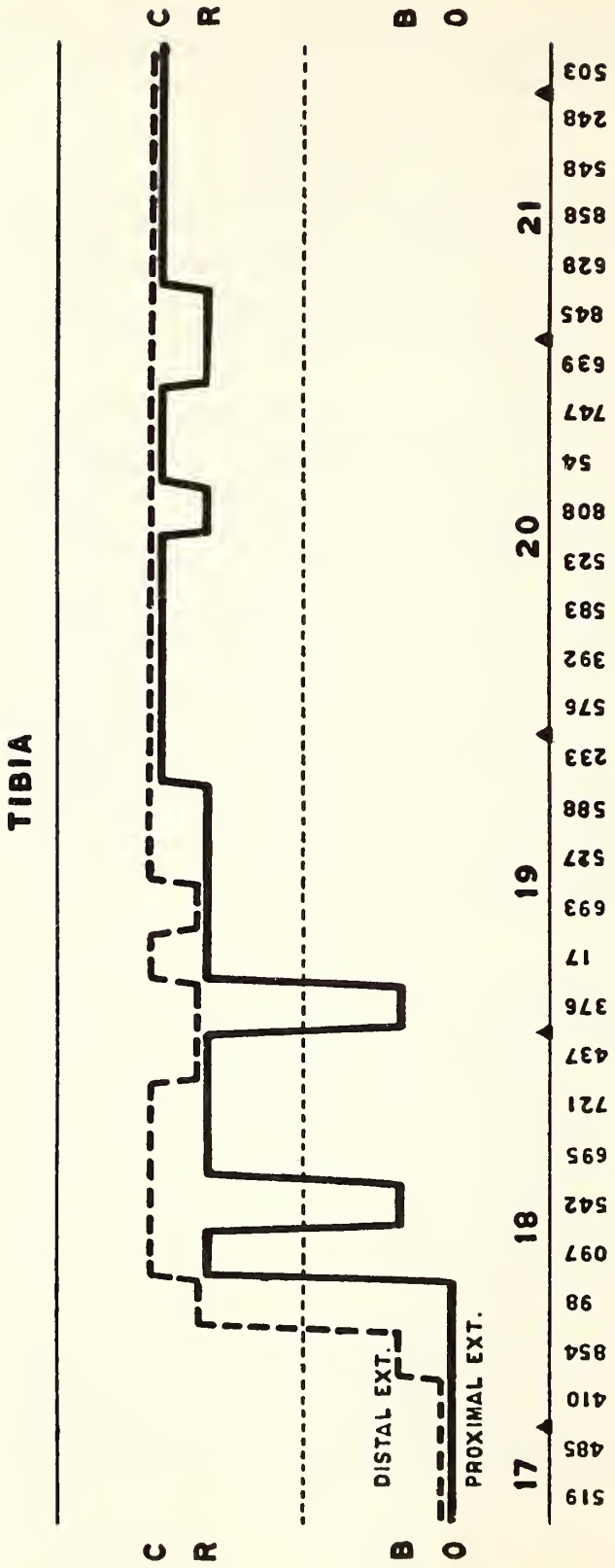

FIG. 5. Age of union of epiphyses of tibia.

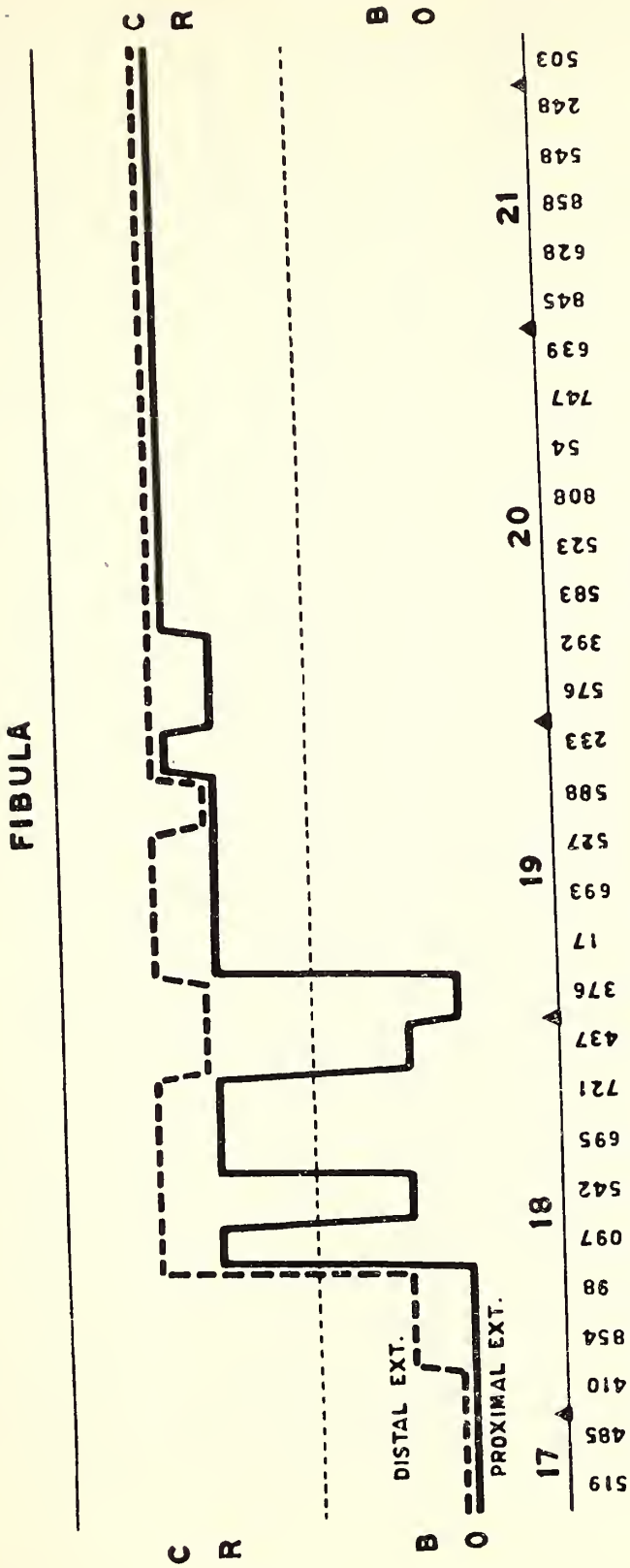

FIG. 6. Age of union of epiphyses of fibula.

result have such definite value as indicators of age that their inclusion in this study is rendered imperative.

SCAPULA
(*Fig. 7.*)

Union of the coracoid with the body of the scapula takes place relatively early in the age scale of epiphyseal union. The evidence (Plate II) shows, in fact, that this process unites very soon after the epiphysis of the distal extremity of the humerus, and not later than the fifteenth year. The constancy in date of union of the coracoid makes it of particular value as an indicator of age.

The acromion not infrequently fails entirely to unite with the scapula. This study shows that when union of the acromion does occur, however, it takes place quite constantly in the nineteenth year. As an age indicator it must be remembered that the acromion is of value only in case it has united.[2]

There remain two so-called marginal epiphyses, occurring at the inferior angle and the vertebral margin of the scapula respectively. These epiphyses behave as two distinct entities in Man as in other primate forms, whatever their true morphological significance may be in other mammalian types. The vestigial character of these marginal epiphyses probably accounts for the relatively great individual variation in the date of their union, a fact which renders them particularly unreliable as indicators of age. The date of union for these varies in different individuals between the nineteenth and twenty-second years.

OS INNOMINATUM
(*Fig. 8.*)

The date of union of the three primary elements, ilium, pubis and ischium, is very constant and constitutes a reliable check, once its proper sequence is understood (v. infra), on other age indicators of the body. A degree of caution must be observed, however, when attempting to determine the stage of union between these three bony elements as the process varies somewhat in different regions, and in the acetabulum in particular is not infrequently complicated by the inconstant triradiate cartilage found in the bottom of this fossa. To eliminate this source of possible error, therefore, all observations included in this study were made on the inside or pelvic surface of the innominate bone, where the lines of union are clear-cut and the condition of union or nonunion

[2]The condition known as separate acromion is not an ununited epiphysis but an anomalous formation of the acromion. This is not the place for an adequate discussion of the anomaly; hence Doctor Stevenson's careful reservation (T. W. T.).

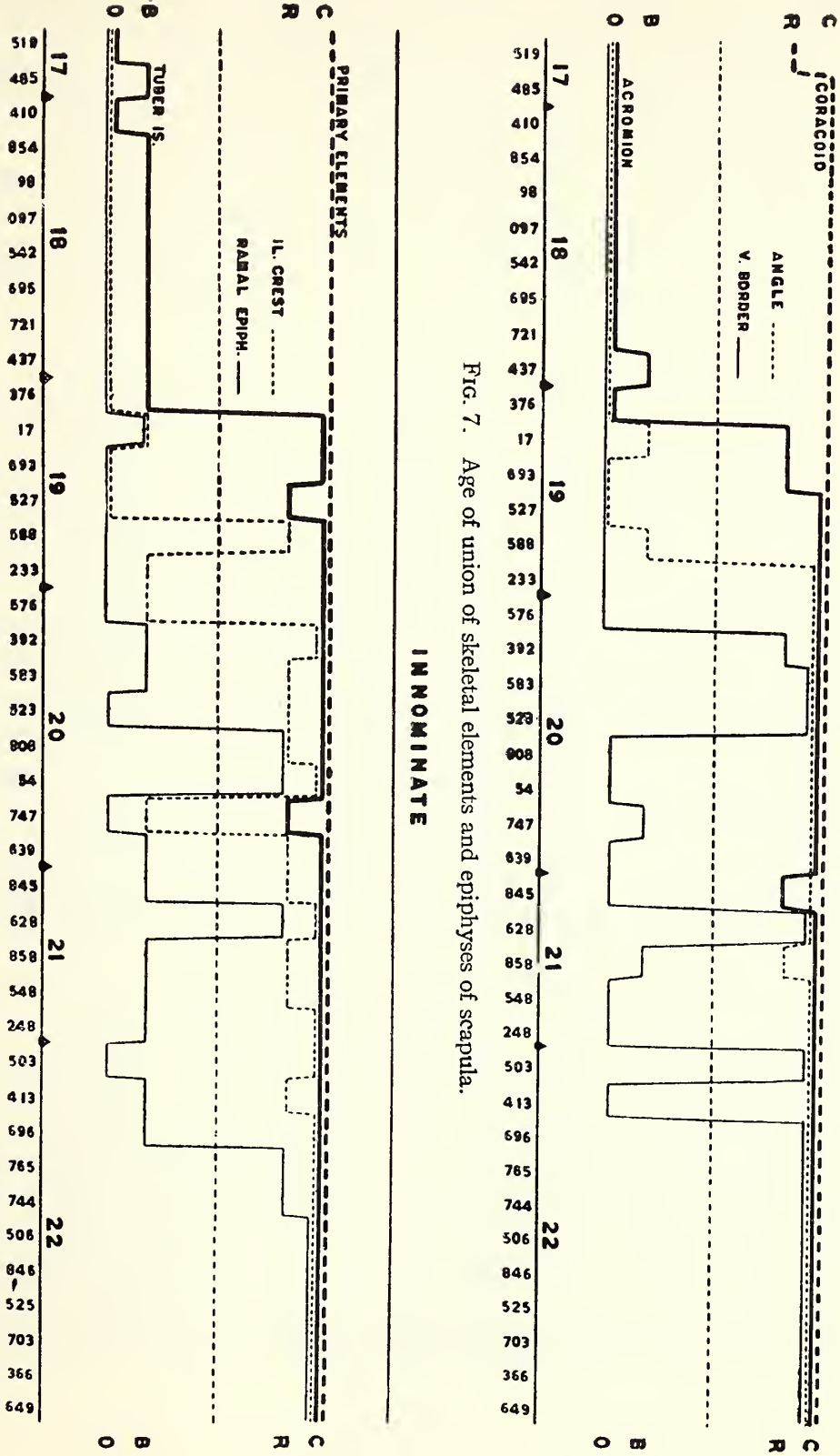

Fig. 7. Age of union of skeletal elements and epiphyses of scapula.

Fig. 8. Age of union of skeletal elements and epiphyses of os innominatum.

definitely determinable. The actual date of union of the three primary coxal elements can only tentatively be stated at this time. From the present study it is evident that it takes place definitely later than union of the distal extremity of the humerus, and is to be assigned (tentatively) to the fifteen-sixteen year period (Plate II).

The epiphysis capping the tuberosity of the ischium begins to unite on the posterior aspect of the tuberosity at the beginning of the eighteenth year. Union only gradually, though quite regularly, extends anteriorly, and is found to be complete from the nineteenth year onward. The constancy of these two phases of union of this epiphysis justifies its inclusion among the valuable age indicators of the body.

There remain two marginal epiphyses of the innominate bone to be considered. The one surmounts the entire crest of the ilium, and results from a rather late union of separate anterior and posterior ossification centers, while the other is a small slip extending ventrally and medially from the tuberosity of the ischium along the inferior border of the joined ischio-pubic ramus. This latter epiphysis is spoken of as the "ramal" epiphysis. The extreme degree of variability found in both iliac crest and ramal epiphyses may be attributed in part at least to the composite nature of the former, and to the vestigial character of the latter. The ramal epiphysis in the human body represents the remnant of a considerably larger element extending the entire length of the ischio-pubic ramus and participating in the formation of the symphysis pubis (v. Todd, '21) in some of the other primate forms. The epiphysis of the iliac crest unites between the nineteenth and twenty-first years, while the ramal epiphysis begins to unite also in the nineteenth year but does not complete its union until the twenty-second year.[3]

In spite of the variability in date of union of these two epiphyses attention might be well called at this point to the fact that the pelvis as a whole records age changes more accurately and over a longer period of time than any other skeletal element in the entire body. At the time that the skull ceases to be a reliable guide to age, namely at the end of the change from deciduous to permanent dentition, the coxal bone first comes into prominence as an indicator of age. Union of its three primary elements occurs at the age of fifteen years. Following this there is a period of activity on the part of its epiphyses extending

[3]This is a valid method of stating the date of union of the 'ramal' epiphysis for it must be remembered that the ramal epiphysis includes more than the vestigial ossifications on the symphysial face. (T. W. T.).

through the twenty-second year, from which time the symphisis pubis becomes an increasingly reliable guide through the thirty-forty year period (Todd, '20, '21, '23), at which time the characteristic lipping of muscle attachments regularly occurs. This period is followed by another only slightly less definite series of secondary changes resulting from the onset of senile absorptive processes which become manifest in the forty-fifty year period. Hence the innominate bone proves a valuable indicator of age throughout a considerable portion of the entire life span.

RIBS

(*Fig. 9.*)

The small scale like epiphyses of the ribs, especially those of the tubercles, present certain difficulties of interpretation of the variable conditions found. The epiphysis for the tubercle, for instance, unites as it ossifies, so that a completely ossified though ununited epiphysis on this process is very rarely seen. The denuded surface of the tubercle, moreover, in cases where the cartilaginous epiphysis is removed during maceration, instead of presenting the rugged appearance typical of a diaphyseal surface exposed though the loss of an epiphysis, is quite smooth and simulates with remarkable closeness the appearance of the united epiphysis itself. Careful study of these particular epiphyses, however, reveals the fact that they unite in most cases in the eighteenth year.

The epiphyses of the heads of the ribs present in a lesser degree the same difficulties as those of the tubercles. After practically two years of fluctuation they are found to be united in all cases after the twenty-second year. The epiphyses of the ribs, in sharp contrast with those of the long bones of the body, are of very little value as indicators of age.

CLAVICLE

(*Fig. 10.*)

The epiphysis at the sternal end of the clavicle has long been considered unique, not only on account of its being the only clearly recognized epiphysis of the clavicle but also because of its delayed union. In addition, this small cartilaginous disc belongs to a type of articular epiphysis often associated with amphiarthroses—symphysis pubis, intercentral joints of the vertebral column, and manubrio-gladiolar articulation of the sternum, for instance—the adjacent epiphyses of which ossify erratically, incompletely, or not at all. It is not surprising, therefore, that this epiphysis exhibits the longest range of activity as

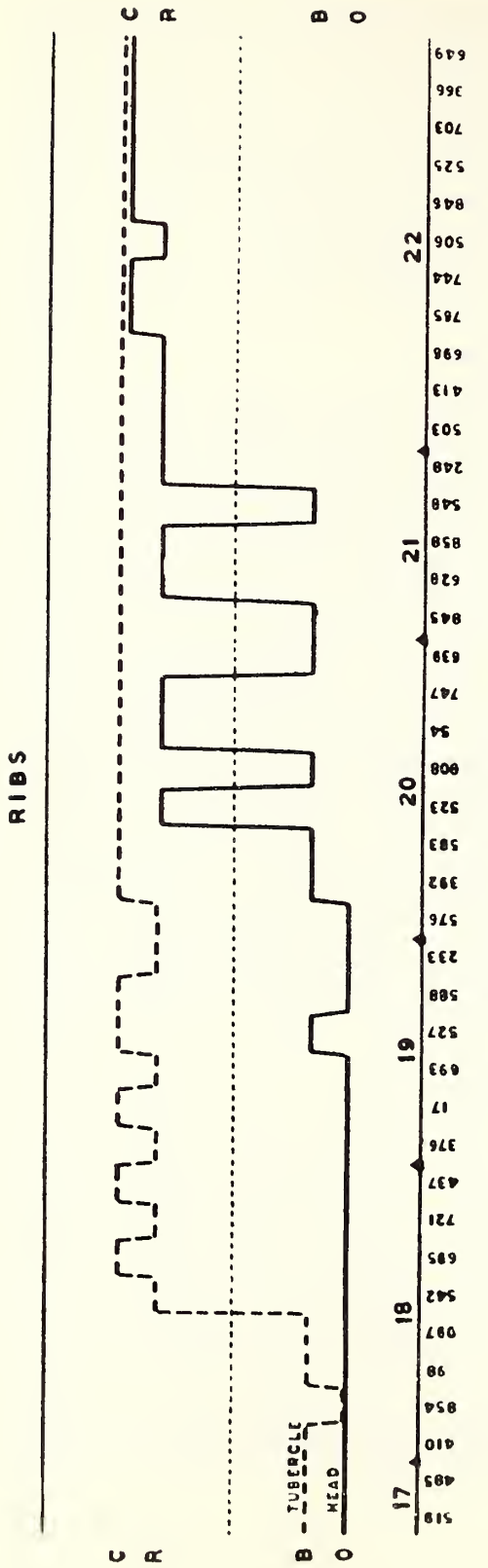

FIG. 9. Age of union of epiphyses of ribs.

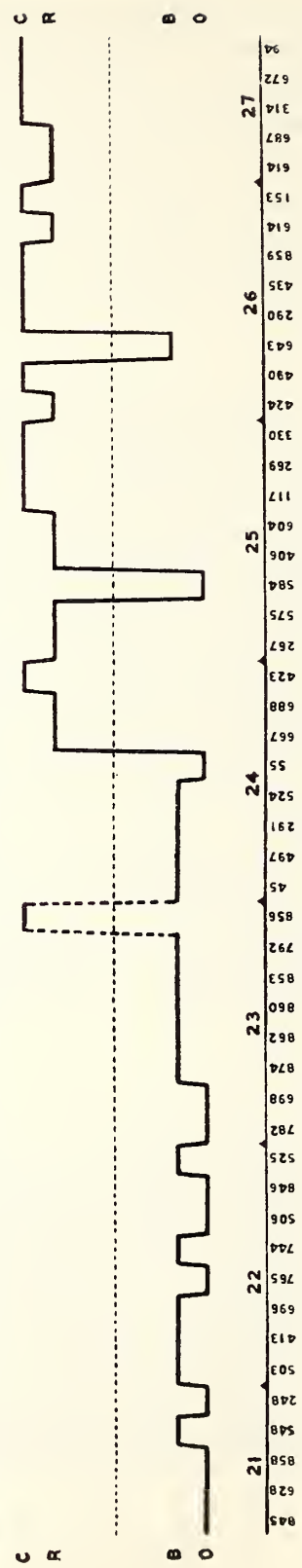

FIG. 10. Age of union of sternal epiphysis of clavicle.

well as the most extensive range of individual variation of any of the epiphyses so far studied. The epiphysis in question shows evidence of beginning union in several of the twenty-two year skeletons, and of having only recently united in several of the twenty-seven year individuals. In fact, it is not until the twenty-eight year old group is reached that this epiphysis is found to be united in all the cases. The usual impression that this epiphysis unites more or less constantly at the twenty-fifth year, and the common practice of considering skeletons to be either older or younger than twenty-five according to whether the sternal epiphysis of the clavicle is united or ununited, seems entirely unwarranted. It is impossible to assign any age at which this epiphysis will certainly be completely united below the twenty-eighth year.

The reader may have wondered that no distinction has been made between the time of union in the different races or sexes in the foregoing survey of the ages at which the various epiphyses unite. Although the material was so arranged and the records so made that such differences might be easily detected and recorded, none presented itself. This finding is at variance with the accepted impression of epiphyseal activity (v. Testut, Poirier, and others).[4] Owing to the relatively small number of cases it is not pretended that the evidence on this point is conclusive. It is very probable, however, that such differences if they exist are very slight, and will be found to resemble in kind and degree the racial and sexual differences in age of appearance of other bodily metamorphoses such as dentition and secondary sex characteristics.

Analysis of the Age Factor in Epiphyseal Union

Several important facts stand out clearly in an analysis of the data just presented. (1) Epiphyses may be divided into two classes: (*a*) those the time of union of which is sufficiently constant to make them safe and useful indicators of age, e. g. epiphyses of the limb bones in particular, and (*b*) a very much smaller group subject to fluctuation in the age at which they unite and hence of little direct value as age indicators, e. g. marginal epiphyses of scapula and os innominatum and also those of ribs and scapula. (2) *The period of life between fifteen and twenty*

[4]The recent assertion by Pryor, made without any confirmatory evidence, that epiphyses in the female unite three to four years earlier than in the male (Differences in the time of development of centers of ossification in the male and female skeleton. 1923. Anat. Rec., vol. 25, p. 268). receives no support in this work. On the contrary the reader is warned against relying too confidently upon the apparent condition of union or of non-union in the radiogram which is merely a confusing medley of shadows.

years is pre-eminently the period of epiphyseal union. No important epiphysis of the first group mentioned above unites outside the limits of this period. (3) Not only are the limits of the above period remarkably constant in the case of all normal individuals, but the time of union of each epiphysis is also relatively constant within this period. (4) Within the total period of epiphyseal activity there is a brief period of intensive epiphyseal union during which a much larger number of different epiphyses are uniting than during preceding or succeeding periods. Fig. 11 depicts the curve of epiphyseal activity based upon the proportional number of epiphyses actually uniting during the respec-

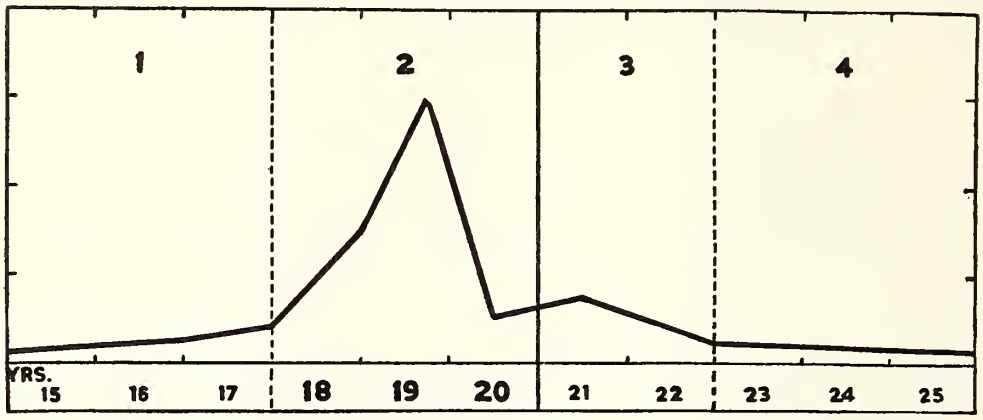

FIG. 11. Curve of relative intensity of epiphyseal activity according to age.

tive phases of the entire period. Up until the age of eighteen, it will be noted, relatively few epiphyses have begun their process of union. The curve rises sharply in the eighteenth year, reaches its peak in the nineteenth year when the largest number of epiphyses complete their process of union, and then falls off rapidly. The abrupt fall in the curve is arrested in the twentieth and twenty-first years by the subsequent period of union of the marginal epiphyses of the scapula, os innominatum and heads of the ribs, while the prolongation of the curve after this point is due to the long drawn out period of union of the sternal epiphysis of the clavicle.

It is of distinct value to emphasize the significance of the fifteen to twenty-year period of life as the real period of epiphyseal union. Upon the basis of such recognition it becomes possible to define three distinct and easily differentiated age periods of adolescent and early adult life, namely, the periods, before, during, and after this fifteen to twenty-year period of epiphyseal union respectively. It becomes also of very practical interest to note that examination of the epiphyses of the

humerus alone suffices to orient quickly and accurately any individual with respect to these three life periods. This is due to the fact that the epiphyses of the distal and proximal extremities of the humerus are the first and the last of the constant epiphyses of the body to unite (v. supra p. 62) and themselves define the lower and upper limits respectively of the fifteen to twenty-year period of epiphyseal union. Absence of union of the distal epiphysis of the humerus indicates that the individual is younger than fifteen years; complete closure of the epiphysis of the head of the humerus, on the other hand, is strong evidence that the individual in question is over twenty years of age. Complete closure of the distal epiphysis associated with nonunion of the epiphysis of the head indicates that the age of the individual is somewhere within the fifteen to twenty-year period.

Further differentiation of age within each of these three particular periods depends chiefly upon (1) the dentition, in those individuals below the fifteen-year limit, (2) a close study and correlation of the stages of union exhibited by the various uniting epiphyses, in individuals within the fifteen to twenty-year period, and (3) in individuals above the upper limit of the true epiphyseal period, upon the stage of union of the marginal epiphyses of the scapula and innominate bone, heads of the ribs and sternal epiphysis of the clavicle, and in particular the symphysis pubis and other metamorphic age changes associated with the pelvis (v. supra p. 72). It is with the second of the above periods that we are particularly concerned and with it the remainder of this section deals.

Individuals within the fifteen to twenty-year period, especially those of the eighteenth or nineteenth years, invariably show all stages of epiphyseal union going on at the same time. This is to be expected when it is considered that all the epiphyses of the body so far studied unite in a comparatively short period of time. The first impression of the epiphyseal activity of this period is apt to be one of apparent confusion of simultaneous events. When several skeletons of the same age are compared, however, it becomes evident that within this group of apparently simultaneously uniting epiphyses there is a definite time order of union. Furthermore, the particular combination of stages of epiphyseal union in the case of any single individual, which can quite easily be presented in graphic form (v. Fig. 12), is essentially the same in all individuals of the same age. The regularity with which particular combinations of different stages of epiphyseal union become associated with definite age periods, and prove constant for all individuals in these

respective age periods, is a fact of primary importance. It provides foundation for the practical application of epiphyseal union to the determination of age in Man.

Plate I presents in graphic form a correlation of these different combinations of epiphyseal stages of union with their specific time of occurrence. It will be noted that the various heights of the graphs in the figures represent the different stages of epiphyseal union mentioned in an earlier section of this paper; namely, (1) the stage of no union, in which case the space is left vacant, (2) the stage of beginning union, (3) the stage of recent union, and (4) the stage of complete union. It should be noted further that the phases of union of the various epiphyses are plotted to represent, not the condition in a particular individual, nor the average of several individuals, but the modal condition, namely, that condition presented by the largest number of individuals of that particular age. This plate is concerned primarily with the date of epiphyseal union, a fact which, in this particular series of skeletons, necessitates placing the lower age limit at seventeen years. The cross-lined figures inserted between those of the definite year periods are interpolated graphs representing borderline conditions occasionally found in either of the two adjoining year periods. This illustrates the full extent of the individual variation found in the date of epiphyseal union.

In this plate the epiphyses of the limb bones and those of the other bones considered are arranged in two groups, differing chiefly in the length of their respective time ranges of epiphyseal activity. The period of active epiphyseal union in the limb bones, for instance, comes to an end with the twentieth year. That of the various epiphyses of the scapula, os innominatum, and ribs extends through the twenty-second year, while union of the sternal epiphysis of the clavicle is just beginning in the twenty-second year and will continue, although not shown in Plate I, until the twenty-eighth year. It must be noted also that only two epiphyses are completely united in the seventeenth year. Although a few additional epiphyses begin their union in the seventeenth year, yet the eighteenth and nineteenth years stand out prominently as the years of active union of the epiphyses of the long bones (also v. Fig. 11).

The innominate bone attracts attention in a study of Plate I on account of having an additional epiphysis beginning to unite in practically every succeeding year after the seventeenth. Thus the tuberosity of the ischium usually begins its union in the eighteenth year, the crest of the ilium in the nineteenth, the ramal epiphysis in the twentieth or twenty-first, and complete union in the latter takes place in the twenty-second

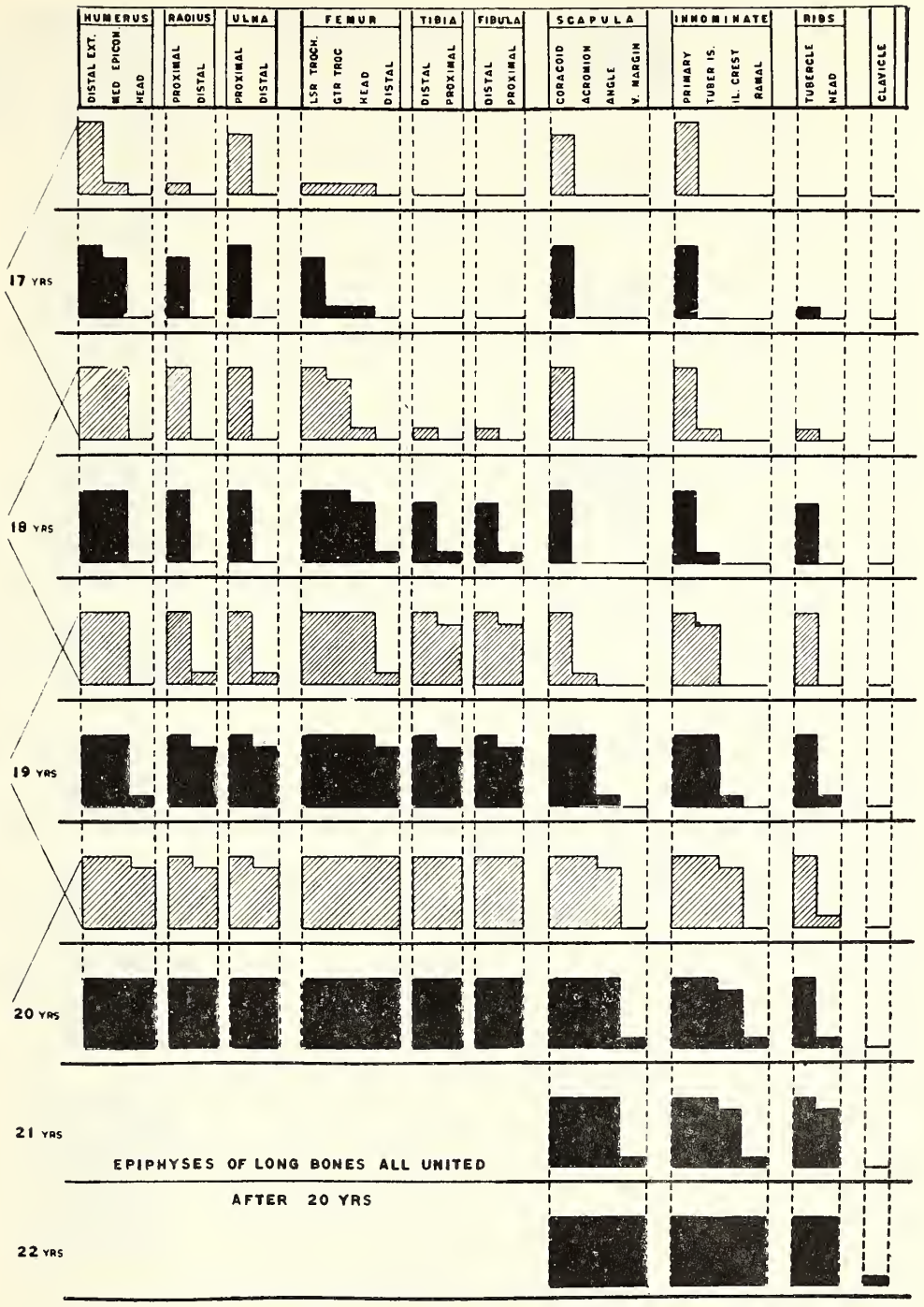

PLATE I. Combinations of phases of epiphyseal union plotted against definite age periods.

year. This successive union of the lesser epiphyses of the os innominatum has proved to be of considerable value in the corroboration of other evidences of age in this particular period.

Application of Data to the Determination of Age

At the outset it may be stated that the determination of age depends not so much upon the condition of any one or two epiphyses as upon the general condition of all epiphyses of the body. In the preceding section the various phases of union of the epiphyses at any particular time were correlated with the definite dates of their occurrence, and the result graphically presented in Plate I. This plate illustrates the close resemblance of the graphs in question to the varying patterns of notches on keys operating the conventional barrel and tumbler locks. A series of keys, each of slightly different notch pattern, and one for each year, is thus presented. Owing to the remarkable constancy in sequence of epiphyseal union, once the process has started, the phases of epiphyseal union for any particular individual when similarly plotted in graphic fashion will present the picture of a key showing a very strong similarity to one or the other of those already plotted from the known-age series of skeletons (Plate I). Use of this simple fact will be made in the paragraphs that follow.

We may now discuss one of the most interesting phases of the study, namely the determination of age in skeletons of unknown age. From an abundance of such material three skeletons will be chosen for examples of this application.

The first is skeleton No. 955, a young negro male for whom no definite age data are available. Taking advantage of the valuable evidence which the epiphyses of the humerus offer in orienting an individual with respect to the period of epiphyseal union (v. supra, p. 77), we first examine this bone. The epiphysis at the distal end of the humerus is firmly united; that of the head shows as yet no sign of union. These facts indicate that the individual is within the fifteen to twenty-year period. In order to interpret the evidence presented by the various stages of epiphyseal union in other parts of the skeleton, the condition of each epiphysis is next plotted in graphic form and the general epiphyseal pattern for this particular individual presented as Fig. 12. When compared with the similarly constructed graphs made from the known age material (Plate I), the epiphyseal key for skeleton 955 is found to fall within the eighteen-year period. The small amount of individual variation exhibited by this specimen is well within the normal limits as

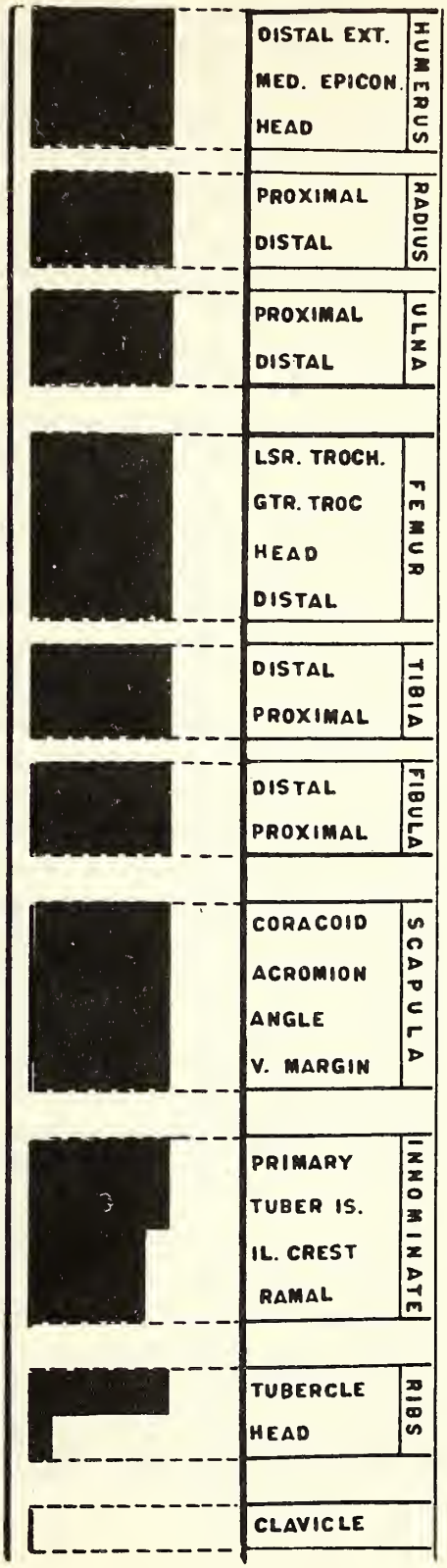

Fig. 13. Epiphyseal key of skeleton No. 0.210.

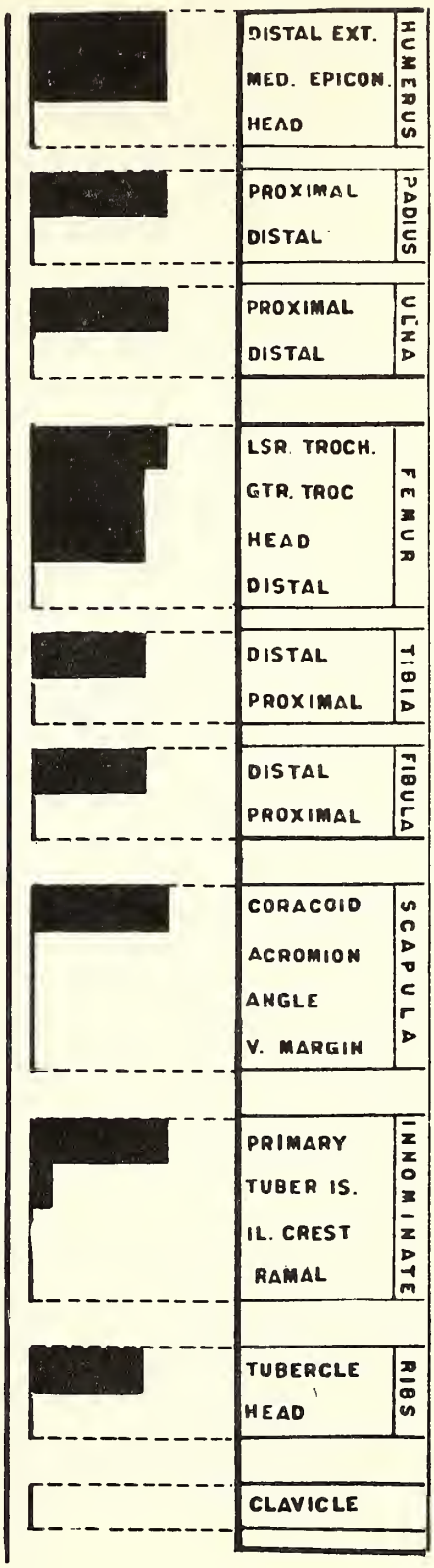

Fig. 12. Epiphyseal key of skeleton No. 955.

indicated by the cross-lined graphs. From the evidence presented by his epiphyses therefore, the young negro in question may be safely said to be eighteen years old. It is doubtful if this could have been determined with as much assurance if the evidence presented by the varying conditions of all his epiphyses had not been correlated in the way suggested above and compared to a standardized age key derived from the study of a large number of definitely age-known skeletons.

The second case is that of a mounted skeleton hanging in the anatomical lecture amphitheater. As to the age of this skeleton, which bears the number 0.210, there is no record of any kind. A rapid survey of the epiphyses of the limb bones reveals the fact that all of these are united, and that the individual may therefore be considered over twenty years of age. A glance at the still patent epiphysis at the sternal end of the clavicle, however, leads to the inference that he was most certainly under twenty-eight, and very probably (v. supra, pp. 73–4) under twenty-five years of age. The scapula, os innominatum, and ribs are next examined as being the sites of continued epiphyseal activity after the epiphyses of the limb bones have become united. The inferior angle of the scapula is firmly united; the condition of the epiphysis along the vertebral margin of the bone is indeterminable on account of its chipped and worn condition. As the epiphyses of both the os innominatum and the ribs show distinct evidence of having not all united, it can safely be inferred that the individual has not yet reached the age of twenty-two. The general epiphyseal status of the skeleton, shown in graphic form in Fig. 13, helps to orient more definitely this particular individual within the now narrowed period between twenty and twenty-two years. The general correspondence of the individual epiphyseal key of skeleton 0.210 to that of the twenty-one year period is seen at a glance. The approach to the twenty-two year period is seen in the recent union of the ramal epiphysis of the pelvis, however, so that the epiphyseal evidence may be said to indicate that this is the skeleton of an individual of certainly not less than twenty-one years of age, and probably nearer twenty-two years.

The third case illustrating the application of the foregoing observations to the determination of age is that of the skeletons of an adolescent female Indian (No. 13) one of a group of skeletons obtained by Dr. Todd, through the courtesy of the Kelley's Island Lime and Transport Co., from a serpentine burial mound on Kelley's Island in Lake Erie. Further interest attaches to this skeleton on account of fetal bones found in situ within the pelvis revealing the presence of twin pregnancy (Fig. 14).

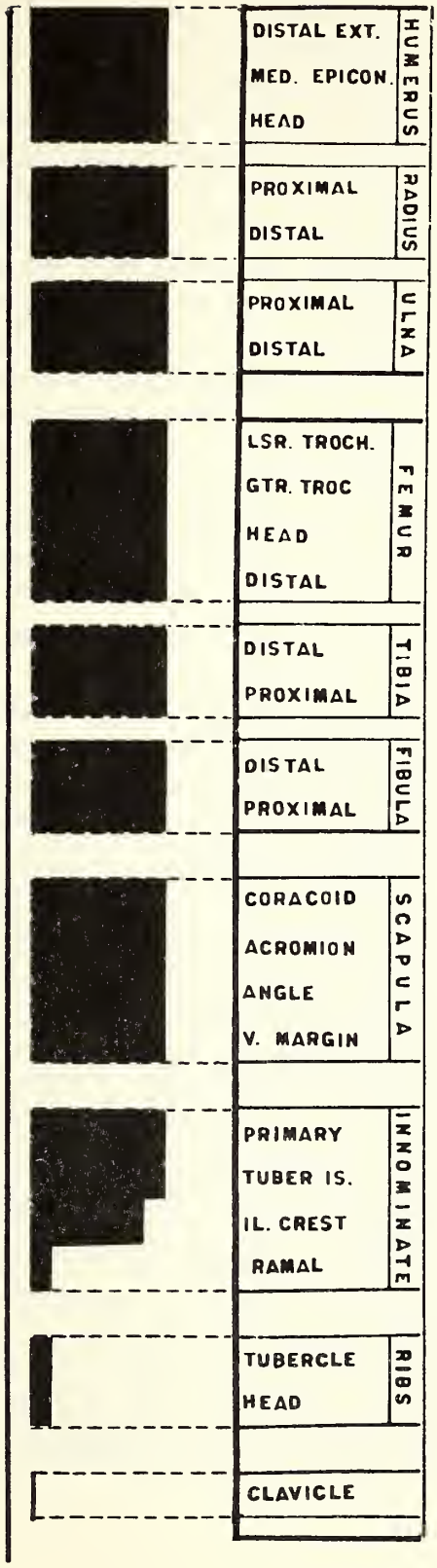

FIG. 15. Epiphyseal key of King Akhenaten.

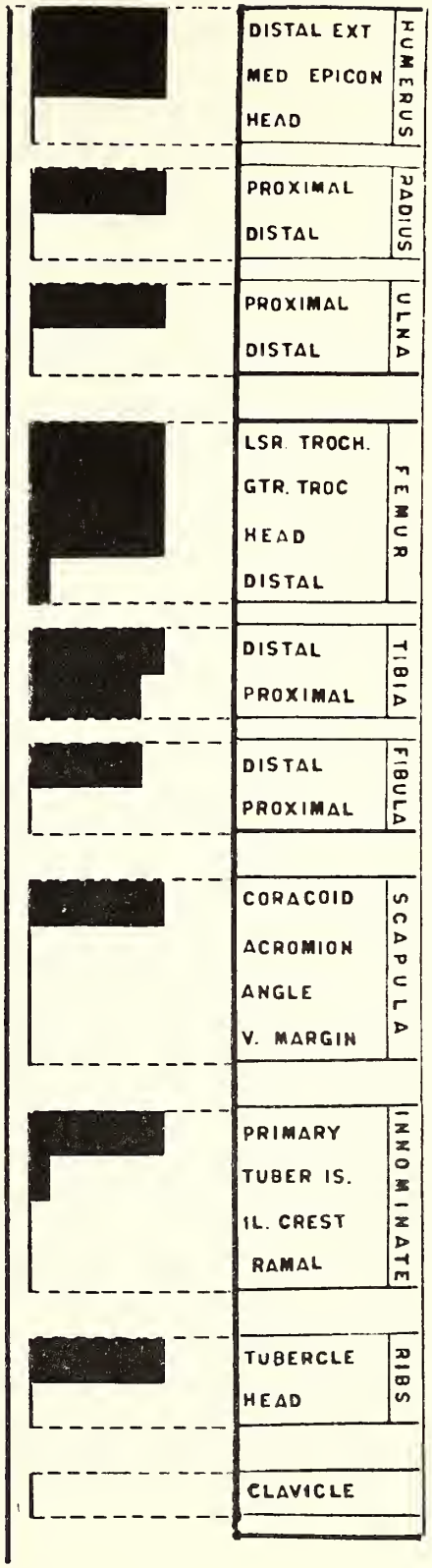

FIG. 14. Epiphyseal key of skeleton No. I-13.

The ends of the limb bones of the skeleton, with the exception of the fibulae, are sufficiently well preserved to afford excellent evidence of the condition of the epiphyses. The scapulae are too fragmentary to lend assistance although the left coracoid is firmly united. Both the innominate bones and the ribs are sufficiently intact to show clearly the condition of all their various epiphyses. A brief survey of the epiphyseal condition reveals at once that the individual was in the very midst of that intensive period of epiphyseal activity in which practically every one of the epiphyses of the limb bones exhibits one or another stage of epiphyseal union. Correlating the combined evidence of all these, and expressing the result graphically in the form of the individual epiphyseal key, Fig. 14, the skeleton is seen very definitely to have been in the middle of the eighteen-year old period. Again it is doubtful if this fact could have been determined with as much assurance if the evidence presented by the varying conditions of all the epiphyses of the body had not been graphically correlated and compared with a standardized age key.

To archeologists and students of ancient history, the question of the age of historical personages at death is often of great moment. A case in point, and one of timely interest, is that of the age of Akhenaten (or Khounaitonou), the heretic king of the XVIII Dynasty of ancient Egypt and the father-in-law of the youthful king Tutankhamen whose royal burial tomb has recently been discovered, and concerning whose own age there is also considerable interest. Regarding the age of Akhenaten, Professor Elliot Smith states first of all that "it is difficult from the anatomical evidence to assign an age to this skeleton sufficiently great to satisfy the demands of most historians, who want at least 30 years into which to crowd the events of Khouniatonou's eventful reign." And further, after carefully noting the condition of the various epiphyses of the body and making a detailed statement of these findings, Professor Elliot Smith concludes, "If we take into consideration all the facts set forth in this statement, not only the data concerning the immaturity of certain bones, but also those of the fully ossified parts of the skeleton; and bear in mind the wide range of variation of the control figures—in some cases as much as ten years between different authorities' estimates of when particular bones cease growing—upon which any argument as to age must be based; two judgments emerge quite clearly from this mass of apparent contradictions: (a) that, if we accept the generally admitted criteria, this skeleton is that of a man about twenty-five or twenty-six years of age; and (b) that no anatomist would be justified in

refusing to admit that this individual may have been several years younger or older than the above estimate, which after all is based upon averages."

No better illustration could be found of the difficulties attending the determination of age by means of comparing the individual epiphyses of a body with the usual confused statements regarding their date of union. From Elliot Smith's very careful description of the condition of union in the case of each of the epiphyses of this royal Egyptian mummy, however, we are able to present the epiphyseal status of the body as a whole in the graphic form of the epiphyseal key shown in Fig. 15. Comparing this with the standardized keys it becomes quite evident, provided that our interpretation of the description and figure of the epiphysis of the crest of the ilium is correct, that Akhenaten at the time of his death was only twenty-two years old. One readily admits, of course, that a persistent sulcus along the cristal border of the ilium may occasionally simulate a delayed union of the iliac crest epiphysis, but in Akhenaten's case this probably has not occurred since the condition of his teeth and cranial sutures also demonstrate that he was quite obviously nearer the age of twenty-two than of twenty-five years.[5]

In this section the writer has endeavored to provide a relatively simple and yet accurate method for the determination of age of adolescent and young adult individuals on the basis of definite knowledge regarding the age and sequence of epiphyseal union. Again it must be emphasized that such a determination depends not upon whether single epiphyses here and there are or are not united, but upon a recognition of the various phases of union simultaneously going on in all the epiphyses of the body, and the determination on this basis of the actual "epiphyseal status" of the individual in question. The graphic method of presenting such epiphyseal findings in the case of any particular individual is herewith suggested as a means not only of determining this epiphyseal status, but also of comparing it when found with suitable standard graphs derived from a study of age-known material. Only in some such way as this can the evidence presented by all the epiphyses be properly weighed, correlated, and applied.

The Sequence of Epiphyseal Union

The reader has probably noticed in Plate I that ten of the twenty-eight epiphyses charted were already in the process of union in the

[5]The evidence of age presented by a study of suture closure is shortly to be published (T. W. T.).

seventeen-year period. This implies a series of still earlier periods, beginning at a time when there are no epiphyses uniting, then successive stages during which the process of union makes its appearance in an increasing number of epiphyses until they have all exhibited the phenomenon in turn. The graphs in Plate II present such a series. In

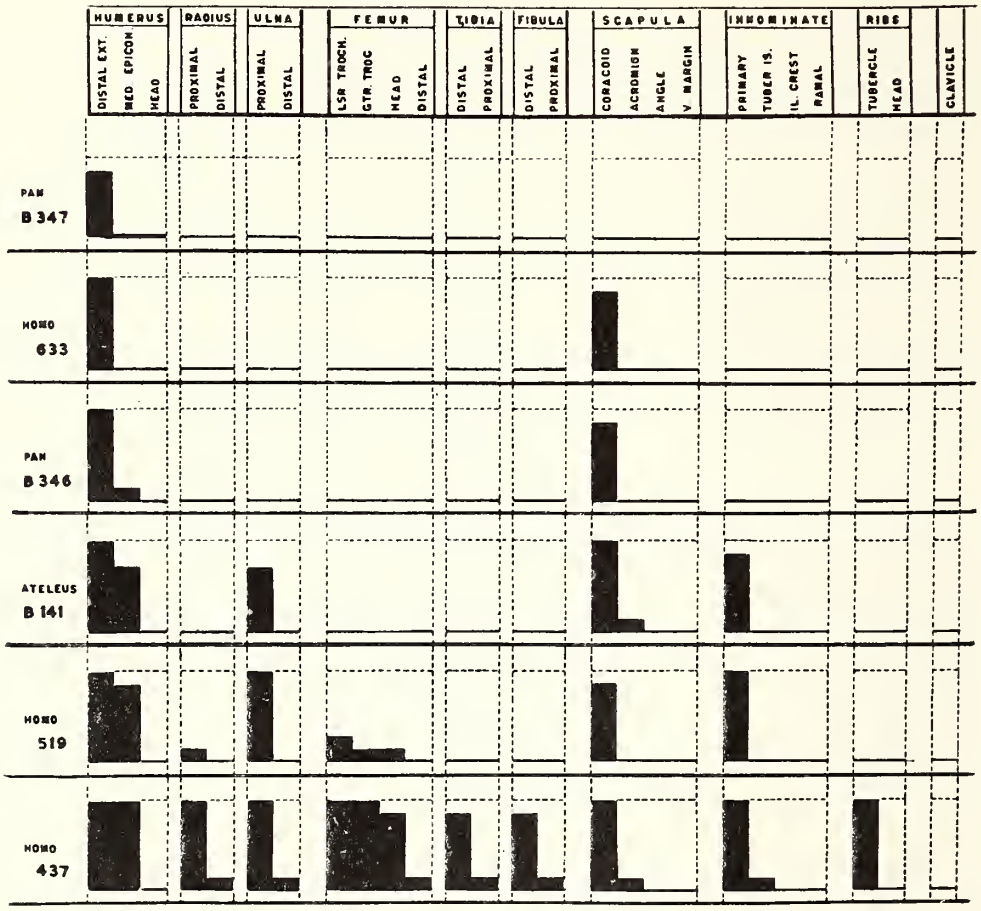

PLATE II. Sequence of epiphyseal union.

this plate the time element is strictly of secondary importance, yet it may be noted that No. 633 is known to be in the fourteen-fifteen year period, and that Nos. 519 and 437 are of the seventeen and eighteen-year periods, respectively. Interpolated between these are other individuals showing intermediate stages where these are necessary to illustrate the sequence in detail.

In the beginning of this series, the epiphysis of the distal end of the humerus stands out conspicuously as the first of the entire body to

unite. Following this there is excellent evidence in the case of several specimens, of which two only are indicated in the graphs, that the coracoid process next unites with the body of the scapula. The medial epicondyle of the humerus, although of the type of epiphysis noted above as exhibiting individual variation more often than those entering into articular formation, does not delay its union long after that of the distal epiphysis of the humerus.

The delay in union of the three primary elements of the os innominatum until after the coracoid and at least three of the four elbow epiphyses are normally on their way to complete union is also conclusively shown by this study. This particular sequence, which can be easily noted in any human or other primate material of the proper age is worthy of special notice in view of the generally accepted impression that the three innominate elements unite at an earlier age than any epiphyses. It was this impression which caused Wood Jones (loc. cit., p. 256), for instance, to class as abnormal those cases among ancient Egyptians in which the lower epiphyses of the humerus were found united in the presence of non-union of the primary elements of the pelvis. The phenomenon in question is nothing other than the perfectly normal sequence of epiphyseal union.

After union of the innominate elements the group of epiphyses at the proximal end of the femur next begins to unite. The period thus ushered in is one of general epiphyseal union during which all the remaining epiphyses except that of the head of the humerus are uniting more or less at the same time. A close examination of the sequence of events in this period, however, shows that the remaining epiphyses of the lower extremity take precedence over those yet to be united in the arm. The distal extremities of the tibia and fibula respectively precede those of the proximal ends of the same bones, while the distal extremity of the femur follows closely after and by its union completes the tale of union of the epiphyses of the lower limb.

In the case of the three epiphyses of the arm still waiting union, namely the two at the distal ends of radius and ulna and that of the head of the humerus, those at the wrist definitely unite before that at the shoulder. The head of the humerus it should be remembered, is clearly the last of the epiphyses of the limb bones to unite. Its union at the age of twenty years marks the close of a distinct phase of epiphyseal union during which all the epiphyses of the limb bones have become completely united.

Passing to the type of epiphyses occurring on the scapula, innominate

bone, and ribs, it is observed that although there is a tendency on their part to exhibit a certain degree of individual variation in date of union a like tendency is not apparent in the sequence of their union. Thus union of the epiphyses at the inferior angle of the scapula always precedes that of the vertebral border of the same bone. In the case of the os innominatum the epiphysis of the ischial tuberosity invariably unites first, then that of the crest of the ilium, and finally that of the ischiopubic ramus. The epiphyses of the tuberosities of the ribs unite first, and are followed by those of the heads only after a considerable lapse of time.

The sternal epiphysis of the clavicle has already been noted as an exception both in the date of its union and length of time during which it exhibits activity. Not beginning until all the other epiphyses are completely united, and further delaying its process of union through a long drawn out and variable period, this erratic member of the family finally brings the program of epiphyseal union to a close in the twenty-eighth year.

Serially summarized the order of union of the various epiphyses is as follows:

Distal extremity of humerus
  (Medial epicondyle of humerus)
Coracoid process of scapula
Three primary elements of innominate bone
Head of radius
  (Olecranon of ulna)
Head of femur
  (Lesser and greater trochanters of femur)
  (Tuberosities of ribs)
Distal extremities of tibia and fibula
Proximal extremity of tibia
  (Proximal extremity of fibula)
Distal extremity of femur
Tuberosity of ischium
Distal extremities of radius and ulna
Head of humerus
Crest of ilium
Heads of ribs
Ramal epiphysis of pelvis
Clavicle

The constancy with which these epiphyses always unite in the same order cannot be too strongly emphasized. Although in a small percentage of cases the process of epiphyseal union as a whole may be slightly accelerated or retarded yet, when the process has once begun,

the sequence of union among the various epiphyses is observed to be exactly the same in every individual.

Fundamental Nature of Epiphyseal Union

As already indicated in the introduction, this study has chiefly concerned itself with certain facts bearing directly upon the date and order of epiphyseal union in the human body. Certain impressions regarding the fundamental nature of epiphyseal union, on the one hand, and the actual relation of this phenomenon to that of growth, on the other, are inevitable by-products of the investigation, and brief mention will be made of them in this section and the one immediately following.

The significance of the facts stated in the closing sentence of the preceding section, however interpreted, cannot be ignored. To ascertain whether or not this constancy of sequence in the union of epiphyses is purely a human characteristic, advantage was taken of the large collection of comparative material in the Hamann Museum at Western Reserve University to study the question of epiphyseal union in mammals generally. Such a study, the details of which will be the subject of a separate publication, not only confirms the constancy of a definite order in epiphyseal union in general but also demonstrates the fact that the particular sequence of epiphyseal union noted above is not a specific, generic, familial, or even ordinal characteristic, but that, although presenting a very few exceptions, it may be considered a general mammalian trait. Further, as I shall show in the section immediately following, the sequence of epiphyseal union remains unaltered in certain pathological states which are known to affect growth but not the appearance of germinal characters. It seems more than probable, therefore, that in sequence of epiphyseal union we are dealing not only with a true *germinal* character, one which is remarkably stable and very primitive.

Although it may be urged with some justice that this question is hereby raised rather than answered, nevertheless the suggestion and the reasons therefor are considered of sufficient value to be placed on record, with the anticipation that further evidence bearing upon this very important phase of the subject will be forthcoming.

Epiphyseal Union and Growth

That there is a relationship, usually considered a very intimate one in fact, between epiphyses in general and the process of growth and that

the union of the former and cessation of the latter are interdependent phenomena, is an anatomical dogma that few have had the occasion to question. Nor, with the seemingly universal acceptance of this view, has there been any real explanation as to just what this relation is or how it functions. It is not the intention of the writer at present to discuss this alleged relationship fully, but to suggest that this relationship exists purely as a secondary association.

Two distinct processes can be recognized as operating in the body; the quantitative process of *growth* on the one hand, and the purely qualitative process of *metamorphosis*[6] on the other. Although each maintains its separate course throughout the life cycle, yet there are times (the occurrence of various phases of dentition associated with more or less definite periods of infancy and childhood, for instance) when these two processes of growth and metamorphosis become more or less synchronous. Because of this secondary association these processes are often considered as one and the same thing. Such changes as fontanelle closure, dentition, secondary sexual changes, and epiphyseal union are all of them metamorphic processes, but because they coincide with certain periods marking off accepted stages in the growth history of the individual they are very commonly considered either the result of, or the cause of changes in the growth process itself.

To distinguish clearly between these two characters, growth and metamorphosis, it is necessary only to take account of those fortunately rare but interesting examples of developmental disharmony in which one of these processes has pursued its normal course while the other has been accelerated, retarded, or inhibited altogether. The indubitable witness of the various dwarfisms, of infantalisms, and acromegaly, to say nothing of a host of more subtle endocrinal distrophies, is that the two processes are not only distinct but also under entirely different control mechanisms. Pathological conditions such as the above are as yet very imperfectly understood, but it is plain that they affect bodily compensations only and not germinal characters, hence the disharmonies. The date of closure of the epiphyseal line does not seem to be associated with the amount or character of bone growth taking place at this region.

The two following cases are typical. The first is that of skeleton No.

[6]Professor Stockard calls my attention to the misleading nature of the term metamorphosis. He points out that the zoologist understands by this term a perfectly well defined process which demands a complete break with former conditions. I readily grant the justice of Doctor Stockard's objection and propose to substitute for metamorphosis, until such time as I can find a more descriptive term, the word which Stockard himself suggests, namely *differentiation*. (T. W. T.)

337, showing growth abnormalities of an undetermined type associated with microcephaly (cranial capacity, 870 cc.) and megacolon in an individual known to have died at the age of thirty-one years. The epiphyses of this skeleton, however, have not yet all united, the general epiphyseal condition of the individual strongly suggesting that usually associated with the twenty-one - twenty-two year period. Cessation of growth in this individual very definitely has not waited until the union of the epiphyses.

The second case, skeleton No. 176, is that of an individual known to be thirty-nine years old at the time of death. This individual in addition to a glabrous facies, retained testes, and well marked indication of infantilism also exhibited a certain degree of gigantism. An osteoma was discovered in his pituitary fossa. The epiphyses, the character of the symphysis pubis, the general condition of the cranial sutures, the vascular pattern of the scapula, and other significant points in skeletal metamorphosis associated with age, all indicate a skeletal age twenty years younger than his known age. The epiphyseal key of this individual corresponds to that of the age of nineteen years. Again the growth process, has apparently not been influenced by nor in turn has it exerted any influence on the process of epiphyseal union.[7]

Summary

1. The essential reliability of epiphyseal union as an indicator of age is established by an intensive study of the phenomenon in a series of definitely age-known skeletons.

2. In respect to their constancy of behavior, and the consequent relative dependability of their union as criteria of age, epiphyses may be divided into two classes.

3. The epiphyses of the so-called long bones (particularly the limb bones) are characterized by a remarkable degree of constancy, and, within the limitations of the period of activity, are to be considered the most reliable of all the various age indicators of the entire skeleton.

4. The epiphyses of another group of bones, namely, the innominate, scapula, ribs, and clavicle, are subject to a certain degree of individual variation in the date of their union and are of value in the determination of age only in the role of corroborators.

[7]Additional evidence of the apparent independence of the control mechanisms of epiphyseal union and growth is to be found among the numerous illustrations of mounted skeletons of dwarfs, achondroplasts, and other growth disharmonies in Gilford's ('11) work on "The disorders of post-natal growth and development."

5. The fifteen-twenty year period may be considered the real epiphyseal period of life.

6. The humerus possesses both limiting epiphyses of this important period, that of the distal extremity being the first and that of the head being the last epiphysis of this period to unite.

7. The age of greatest intensity of epiphyseal activity is the nineteenth year.

8. The os innominatum is the site of a larger number of reliable age indicators than any other skeletal entity of the entire body.

9. The accurate determination of age by observation of epiphyseal union depends not so much upon the condition of any one or two epiphyses as upon the correlation of the various stages of union found in all the epiphyses of the entire body.

10. The correlation of the various stages of union found among the different epiphyses of an individual at any particular time is most easily accomplished by a simple graphic representation of the varying stages found. By comparing the resulting "epiphyseal key" of the individual with a chart of seriated known-age keys the age of the individual in question is accurately determined.

11. The sequence of union among the various epiphyses is definite and constant.

12. This same sequence of epiphyseal union is found quite generally throughout the majority of other mammalian forms, and appears to be a remarkably constant and primitive mammalian character.

13. The phenomenon of epiphyseal union is essentially one of differentiation and should not be confused with the process of growth which manifests itself at the epiphyseal line. The control mechanisms of the two processes appear to be distinct.

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TIME OF APPEARANCE AND FUSION OF OSSIFICATION CENTERS AS OBSERVED BY ROENTGENOGRAPHIC METHODS

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INTRODUCTION

A PERUSAL of the various anatomical authorities shows a very striking discrepancy regarding the ages at which the different ossification centers appear and the various epiphyses first become calcified and fuse with their respective diaphyses. In former years, the only method of examination of the epiphyses was to study the dead subject, but opportunities of doing this on an extensive scale were, and still are, very rare, and in any case it is not always a simple process to determine by ordinary inspection whether an epiphysis has been present or not. Moreover, with the exception of a study by Stevenson on a rather limited number of dried skeletons, no such attempt appears to have been made. However, it is by means of a roentgenographic examination that not only are the ossific centers more clearly and more certainly demonstrable in most cases in the living subject, but a larger series, with exact information concerning the respective ages can be more easily studied and compared.

It has been felt that a much more accurate and authoritative account of the dates of appearance and fusion of ossific centers than is at present available would be of very great value for comparative purposes, especially in investigations concerning racial differences, effect of environment and climate, and for clinical and medicolegal purposes. It is hoped that this may stimulate further research in various directions, and such research will have a value in direct proportion to the accuracy with which the observations are recorded.

ALTERED TIME OF APPEARANCES OF OSSIFIC CENTERS IN ENDOCRINE DISTURBANCE

Only recently has the great importance of the study of the time of appearance of the ossific centers been appreciated in the study of endocrine disturbance, more particularly by Shelton, while Clark has shown the effects of such conditions as hypothyroidism, macrogenitosomia, gigantism, etc., and illustrates in a striking manner with the aid of roentgenograms (Fig. 1) the appearances of the epiphyses both before and after endocrine therapy. He is, however, under the quite unjustified impression that the study of the development of the epiphyses by roentgenological means has been fairly exhaustive and quotes some of the authorities which are mentioned and criticized below, and also includes reference to a somewhat inadequate chart by Camp and Cilley embodying the "opinions" of numerous authorities from the textbooks not only prevailing at the time, but even now still to be found in the latest editions of such works. In rare instances only is it possible to trace the source of the authors' information in such textbooks and it appears that the periods are founded rather on vague guesses than upon careful investigation.

INFLUENCE OF DIET AND HEALTH

Francis studied particularly selected groups of children, 25 each males and females in each of four groups, namely (*a*) breast fed, (*b*) not breast fed, (*c*) those with gastrointestinal disturbance and (*d*) those dead as the result of severe illness. In this

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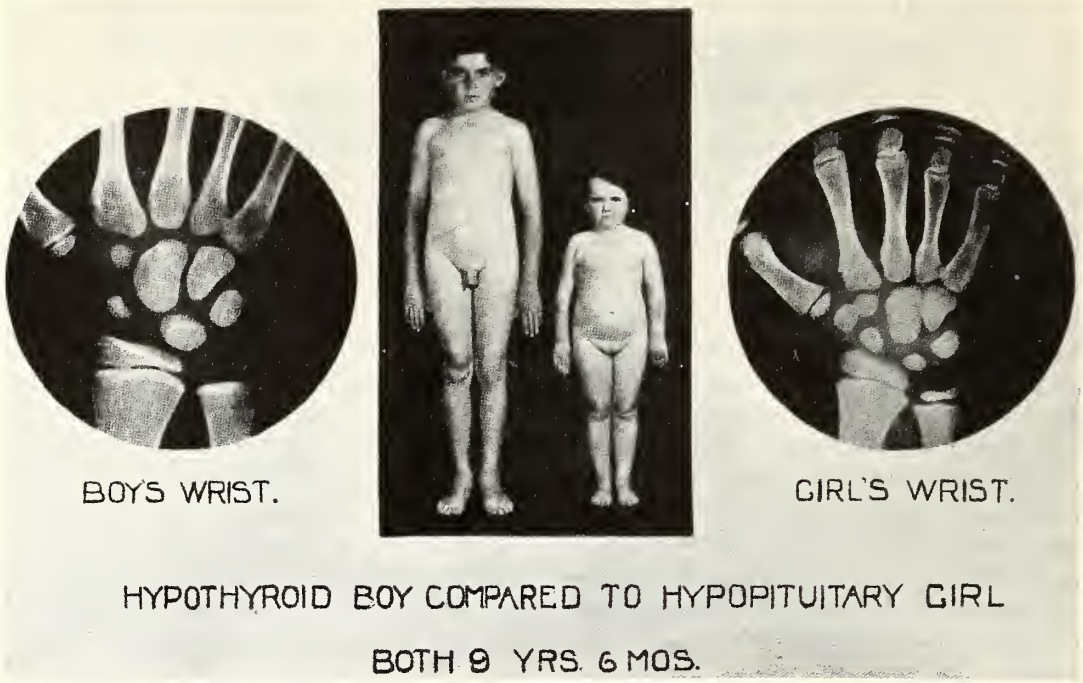

Fig. 1. Hypothyroid boy compared to hypopituitary girl. Both aged nine years six months. (Courtesy of Dr. D. M. Clark, Santa Barbara, California.)

comparative study of the degree of epiphyseal ossification in infancy under varying conditions of diet and health, he came to the very important conclusion that "Epiphysial ossification is a more delicate objective indicator of constitutional health than is progress in height or weight," and that "severe or prolonged illness holds back general progress, but epiphysial ossification shows the greatest retardation."

Similarly other influences, especially nutritional and general pathological disturbances exert a considerable effect on these centers. By careful study of the epiphyseal centers, further research is bound to indicate various incipient pathological states at a much earlier stage than hitherto.

WORK OF OTHER INVESTIGATORS

I can nowhere find accurate statistics actually based on the number of subjects examined with the exception of Galstaun, Sidhom and Derry, Pryor, Menees and Holly and Adair and Scammon, and more recently by Francis and Werle, and also by Hill. It should be pointed out that no reliance should be placed on opinions or data which are not based on careful roentgenological observations.

Galstaun presented the results of investigation of about 100 Hindu and Anglo-Indian girls aged 13 to 19 years, the work being limited to the regions of the elbow, wrist and hand. His figures have been made use of for the purpose of comparison, but these show no very great disparity with the series presented here.

Sidhom and Derry investigated the union of some of the epiphyses of the upper limb in over 400 Egyptian boys, mostly between the ages of 14 and 20, being, like Pryor, particularly accurate in recording their ages. The boys were especially examined for the purpose of their research. As compared with boys in the Australian series, the majority were fused at the same age in the case of the medial epicondyle and of both extremities of the radius, a year earlier for the lower conjoint epiphysis of the humerus, distal epiphysis of the ulna and

for the first metacarpal, and two years earlier for the distal phalanx of the thumb. With regard to the extremes, there were instances of both earlier and later fusions in the Egyptian series.

The work of Pryor, however, is of monumental importance, for, as the result of a study of 554 roentgenograms of the hands of children from 3 months to 14 years of age, he came to the following striking conclusion: "The bones of the female ossify in advance of the male. This is measured at first by days, then months, then years," a conclusion which is abundantly confirmed elsewhere. Moreover, he has carried his research further and, in studying the roentgenograms of 140 fetuses from ten and a half to 38 weeks of age, 71 being male and 69 female, reached the very unexpected result that "in the embryo and throughout intrauterine life, progressing from days to weeks and months." Such advances apparently take place even before external sex differentiation can be determined.

Although abundant evidence of the advance in females is present from the period after birth, Pryor does not give any data regarding such priority from "the earliest developments of centers of ossification." In the series of fetuses which I examined the priority of the female is clearly noted and is referred to in the text under the appropriate headings.

Menees and Holly have examined 500 films taken of infants within 48 hours after birth, all over 2 kg. in weight and 39 cm. in length with a menstrual age of at least 255 days. Of these, 263 were males and 237 females, and included 2 negroes. The centers for the head of the humerus, coracoid, capitate, hamate, head of femur, distal epiphysis of femur, proximal epiphysis of tibia, cuboid, and third cuneiform were especially noted.

Adair and Scammon have also examined a smaller series of 45 females and 55 males within 48 hours after birth, the females varying in weight from 2,185 to 4,440 grams and in length from 43 to 54 cm., the males 2,080 to 5,060 gm. and from 42 to 54 cm. in length. The examination was confined to the distal femoral and proximal tibial epiphyses, cuboid, capitate and hamate.

Stevenson studied the periods of fusion only in 110 skeletons aged between 15 and 28 including 83 from 15 to 25 years of age. He makes the following extraordinary criticism of the roentgen examination, which is quite unjustified: "The recent assertion of Pryor, made without any confirmatory evidence, that the epiphyses in the female unite 3 to 4 years earlier than in the male receive no support in this work. On the contrary, the reader is warned against relying too confidently upon the apparent condition of union or non-union in the radiogram which is merely a confusing medley of shadows." However, as Stevenson has not separated the skeletons of the females from those of the males, his work is not of value for the purpose of comparison with the Australian series, and in any case, of the 110 subjects between 15 and 28, but 20 are female, of whom 18 are between the ages of 15 and 25. Many of the conclusions arrived at can be readily challenged, particularly the alleged constancy of behavior of the epiphyses with regard to the ages of fusion. His work adds no information of value in the studies of epiphyses, but is included as a sample of the poor kind of research upon which our previous knowledge rested.

Borovansky and Hnévkovský investigated the bones of both the upper and lower extremities of 352 boys of all ages up to 19 years, the roentgenograms being especially made for the purpose of the research. Even with this limited material, all of boys from Prague, charts representing the periods of ossification are shown, although the actual number at each age is not given. The work, however, is valuable, inasmuch as many measurements of the size of the various epiphyses at different ages are given.

Paterson has investigated about 1,000 roentgenograms and roughly tabulated his results, although he gives no actual statistical figures.

Davies and Parsons have described the

appearances of epiphyses as seen in roentgenograms, giving detailed information of the ages when these were seen, but no numerical data from which the relative frequency can be ascertained are given. Unfortunately, the sexes of the individual examples are more frequently omitted than inserted in the text.

An immense advance in method of investigation has been initiated by Francis and Werle who examined 307 male and 315 female white American children of the "economically stable" class, all selected on account of their normal health, of "good heritage, favorable environment and abundance of protective foods," and under the supervision of a pediatrician. Roentgen examinations were undertaken at 3, 6, 9, and 12 months and thence every 6 months until the age of 5 years, the maximum number in any age group being 104 girls and 96 boys, the minimum 55 girls and 39 boys. Despite the fact that these examinations were only carried out at not less than 3 month intervals, the ages of appearance of centers is given at various intermediate intervals such as 2, 7, monthly from 10 to 16 months, etc. Moreover, it is stated that in compiling standard tables for the age and sequence of appearance of ossification centers, the age given was that shown when 20 per cent rather than 50 per cent were present, but the reason for this is not apparent. Possibly they regard the earliest age as the optimum. However, it is frequently stressed that delay in the appearance may be caused by such disturbance as illness, endocrine dysfunction, malnutrition, etc., and no doubt this is exceedingly important and accordingly, in their opinion, conclusions of normality based on examination of hospital patients is fallacious.

Although the use of roentgenological examination has been practiced throughout the world for well over 44 years, it is a remarkable fact, that despite the millions of exposures which must have been made in subjects of all ages and in all regions of the body, no really comprehensive survey of the osseous development has even been attempted. There are some regions, more particularly the vertebrae, which have scarcely been touched, and surely it is not creditable either to the roentgenologists or to the anatomists that everywhere in the literature one still finds the same prevailing condition of hopeless confusion, inaccuracies and inconsistency as were present before Roentgen made his great discovery. All the work listed above is quite limited in scope and to a limited number of joints only, and nowhere is there sufficient quantitative information to justify the establishment of any percentage computation, much less the charts which have appeared and still continue to appear in a number of instances.

That recent publications still continue to ignore the evidence produced by more precise investigation is shown by the Tables of Ossification given by Appleton, Hamilton and Tchaperoff, where, for instance, the union of the femoral head is given as 18 to 20 years, yet in the majority these are fused at the age of 14 in girls and 17 in boys. This table shows fusion of the acromial epiphysis as well as the epiphyses for the tuber ischii and iliac crest at the 25th year although in my series, the acromion is shown to be fused in the majority of both sexes at the age of 17 and the tuber ischii and iliac crest at the age of 21, the latter at 20 in females.

MATERIAL EXAMINED

The subjects of this examination were mostly hospital patients, practically all of whom are of European descent, and as nutritional disease such as rickets, scurvy, etc., are not of great frequency in Australia, the error from including such possible conditions is not considerable. To avoid duplicating details of the same subjects, and to assist in checking off age and sex particulars, the names of the individuals and serial numbers of the films were also recorded. Where possible, the actual date of birth of the subject was ascertained, so that the age to the month is given. In the earliest series, this was not done and in these cases the ages are given in years only. Notes are

made only of such centers, the presence or absence of which could be definitely established, and all others, that is those about which there is any doubt at all, are excluded from the records. The majority of this material was obtained from the Prince Henry Hospital, Melbourne.

In addition to the above, a series of about 50 fetuses of varying sizes from 30 to 334 mm. ($8\frac{1}{2}$ to 38 weeks) has been examined. As it is impossible to ascertain the exact ages of these, the lengths only are to be considered as accurate, but the ages in weeks have been roughly estimated according to the investigations made by Keibel and Mall and are inserted in parentheses. (One specimen measuring 32.5 mm., however, was aborted 49 days after a single coitus.) The great bulk of material from which these observations were made was obtained from the Women's Hospital, Melbourne, and I am indebted to their radiologist, Dr. Colin MacDonald and to the Medical Staff generally for much valuable assistance.

In 2 only of the series was air found to be present in the lungs, both in females of 298 and 315 mm. in length ($33\frac{1}{2}$ and 36 weeks) respectively, although the lungs were airless in 5 female and 6 male fetuses of a length of 294 mm. (33 weeks) or longer. Air was likewise present in the stomachs of both of the former female fetuses as well as in those of 11 other fetuses of which 5 were female and 5 male of various sizes, the smallest being a male of 147 mm. (18 weeks) and a female of 205 mm. (23 weeks), in none of which had breathing commenced as shown by the absence of air in the lungs. It is believed that the air is swallowed and it is consequently inferred that the fetus was living at the moment of birth (Fig. 2). That the gas is not due to putrefactive processes is indicated by the fact that the fetuses when examined were fresh, the stomach being always filled before any part of the intestines and that no fetus smaller than 147 mm. (18 weeks) showed the presence of gas in the stomach. One can therefore infer that the process of swallowing air

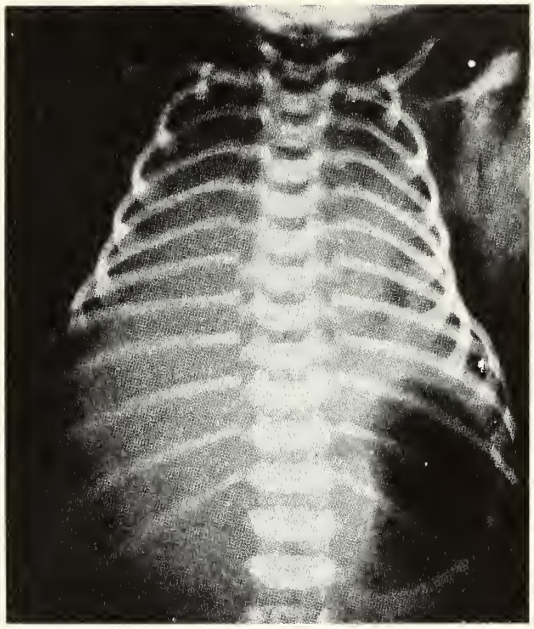

Fig. 2. Female, 304 mm. (34 weeks). Although there is no air in lungs or intestines, air is present in the stomach. Although no breathing has taken place, fetus has swallowed air, which is evidently not due to putrefaction.

precedes (probably invariably) that of breathing, and that many fetuses (11 in this series) swallow air, even when through some reason or other they are unable to breathe, although it is possible that the manipulative attempts to force the newborn child to breathe merely causes it to swallow air but it seems unlikely that such an attempt would be made on a fetus as small as 147 mm. (18 weeks) in length.

PRESENTATION OF RESULTS

The ideal method of presenting the results of such an inquiry would be by means of graphs, but the material available is not nearly sufficient for the purpose, although Stevenson prepared graphs for a very much smaller series. To give percentages, even roughly, where in no instance are there 100 subjects in any age group is likewise objectionable, although authors, notably Paterson, have done so. Many such percentage computations must be sheer guesswork and appear to have been made even

Fig. 3. Male, aged six years eleven months. Multangulum majus is well marked on left but completely absent on right; lunate just appeared on right, but no trace on left. (Courtesy of *Journal of Anatomy*.)

when less than a dozen subjects were under review. The only honest, and it is thought the best, method is to give the actual figures in each age group, and this has been done. Later on, should a vastly larger series be studied, percentages and graphs may be given with confidence as to their relative accuracy.

Stevenson and Paterson have both summarized in considerable detail the ages of appearance and fusion of the different epiphyses as given by numerous authors. Although this is very useful as serving to illustrate the various discrepancies, a repetition of such lists would otherwise serve no useful purpose, and it would be better to discard all data except those based upon actual statistics, for attention has already been drawn to the confusion still existing everywhere in the literature.

With regard to the various descriptions which follow, the following points with reference to each sex have been specially noted:

(a) Ages of youngest subjects in whom ossific centers in question were found to be present.

(b) Ages at which in at least half of the individuals centers were found to be present.

(c) Ages of oldest subjects in whom epiphyses were found to be fused with the diaphyses.

(d) Ages of youngest subjects in whom epiphyses were found to be fused with the diaphyses.

(e) Ages at which in at least half of the individuals epiphyses were found to be fused.

(f) Ages of oldest subjects in whom epiphyses were found to be fused with the diaphyses.

The only ages given are those at which there are found to be variations. At other ages, the centers have been found to be either all present or all absent.

RIGHT AND LEFT SIDES

Though classifications have been made regarding the sex, and notes have likewise been taken with respect to the sides, whether right or left, any classification regarding the two sides would considerably burden this work, but as yet no detailed study has been made concerning the possibility of any appreciable difference of one side as compared with the other. Moreover, it is doubtful whether any appreciable difference exists, although it is quite conceivable that the different function of one side compared with the other, for instance the use of the right upper limb in preference to the left in right-handed individuals, might lead to some variation of the times of appearance of ossific centers. It has been noted repeatedly that an ossific center is present on one side although absent on the other in the corresponding bone of the same individual. Of 25 such examples, the centers were noted 16 times to be present on the right side but not on the left, while in the other 9 they were present on the left but not on the right.

Menees and Holly traced 11 infants with asymmetrical development of epiphyseal centers (7 times present on the right side and 4 times on the left, in each case being absent on the opposite side) and found that the hand preferred for use coincided in 9 instances with the side on which the epiphysis or center for the carpal bone was present and differed in the other 2 instances. In one case, the center was present for both

the head of the humerus and cuboid on the right side but not on the left. It would certainly be impossible to account for these occurrences on the score of endocrine or of any other general disturbance.

In the most recent work by Francis and Werle, the left sides only were examined, it being assumed for practical purposes that both sides are alike, but that this is not invariably the case is shown by numerous examples.

ORDER OF APPEARANCE

Köhler has stated that the order of appearance of epiphyses is not necessarily the same upon both sides, even in the same individual, as may be noted in the example of the carpal bones of a boy aged 6 years and 11 months quoted later on (Fig. 3) in the series where the multangulum majus is well marked on the left, but completely absent on the right and, although the lunate has just appeared upon the right, there is no trace of this carpal on the left. This does not accord with Pryor's observations, which are accepted by Francis and Werle: "Regardless of the variations (normal) the ossification is bilaterally symmetrical." It would be difficult to account for the asymmetry on account of illness (unless localized to one side), endocrine dysfunction, diet, etc. Nor are they necessarily the same in twins, as shown by Borovansky and Hnévkovský, who figure the hands of twin boys aged 6, where in one boy, the navicular was present on one side, but not on the other, and was absent on both sides in the brother. In the first boy the multangulum minus was present on both sides, but absent on both sides in the brother.

Fig. 5. Same individual as that in Figure 4. Note date May 29, 1930. Suture line between epiphysis and diaphysis now completely disappeared.

Fig. 4. Male, aged sixteen. Note date December 16, 1929. Well marked interval separating olecranon epiphysis from diaphysis. Compare with Figure 5. To illustrate time of closing.

TIME OF FUSION

With regard to the time of fusion, that this process usually occupies only a few months seems to be indicated by an observation of the epiphyseal plate between the tip of the olecranon process and the

diaphysis of the ulna in a subject aged 15 which showed as a considerable gap on the roentgenogram on December 16, 1929 (Fig. 4), but on May 29, 1930 (Fig. 5) not the slightest trace of the epiphyseal line could be detected, despite the particularly favorable view one obtains of this center in the lateral view. I believe that Galstaun's classification into "commencing union," "earlier stage of same process," "nearly complete union" and "union just complete," is superfluous and unnecessarily complicates the observations. I have merely noted non-fusion or fusion, the latter referring to entire disappearance of the epiphyseal plate, which is in most cases not difficult to determine. A linear shadow which may sometimes persist even for years at the junction of epiphysis and diaphysis is interpreted as fusion. When comparing Galstaun's records, his classification "union just complete" is included with fusion, and the other descriptions as non-fusion. Stevenson, as well as Sidhom and Derry, has likewise described several stages of fusion.

In all ages in this series, the ages quoted are the ages at the last birthday.

PERSISTENT EPIPHYSIS

It is rare indeed that any of the important epiphyses, such as the main proximal and distal epiphyses of the long bones, persist throughout life, yet some of the minor, and also the rarer ones do occasionally persist, more particularly those at the tips of the various processes of the vertebrae. The persistence of the rarer epiphyses at the base of the fifth metatarsal, and the posterior tubercle of the calcaneum occurs but seldom.

MATURATION STUDY

Todd has brought out an Atlas of Skeletal Maturation limited to the hand, showing the appearance at varying ages from birth until maturity, and divided into different stages of maturation. Since Todd's death, similar atlases are being prepared for other regions.

Table I

Age Groups	Females			Males		
	(a)	(b)	(c)	(a)	(b)	(c)
Under 10	85	11	12.9	149	9	6.0
10 to 19	137	15	10.9	195	13	6.7
20 to 29	106	12	11.3	111	7	6.3
Total	328	38	11.6	455	29	6.4

THE HEAD

METOPIC SUTURE

An examination of posteroanterior projections of 783 skulls at all ages from birth up to 29 years was made to determine the history of fusion of the two halves of the frontal bone in the middle line at the metopic suture. Table 1 indicates the frequency of existence of non-fusion in each sex in each age group respectively.

(a), (b) and (c) refer to numbers of subjects examined, numbers of unfused sutures and percentages of non-fusion in each sex in each age group respectively.

From Table 1, it is apparent first that the unfused suture is found nearly twice as frequently in the female as in the male, and secondly that there is no considerable difference in the frequency in any of the age groups, the small preponderance of sutures in the females under the age of 10 possibly being due to the relatively small number of subjects examined in this group. It therefore appears evident that when fusion of the sutures takes place, in the vast majority of instances it occurs within a few

years of birth and only rarely later on in life, and that if fusion does not take place early it probably persists in most instances until late in life (Fig. 6).

SEMICIRCULAR CANALS

Hill has shown in a study of fetuses that the semicircular canals were not ossified in 3 fetuses of an estimated age of 8 weeks, that of 19 estimated aged 12 weeks, 12 showed this feature, while of 32 estimated 16 weeks old, all showed these canals. In older fetuses, these canals become increasingly obscured with advancing mineralization of the squamous and petrous temporal.

HYOID BONE

Hill has noted the presence of this bone in the fetus at 20 weeks' gestation in both sexes. He has observed them at this period in the white race as well as in negroes. It is not invariably present at full term in either sex, or in either the white or negro race.

VERTEBRAL COLUMN

It appears that no systematic roentgenological study of the ages of appearance for the centers of the vertebral epiphyses has ever been made—at least such has not been discovered in the literature. Only a few very brief and incomplete notes are included here. Somebody, it is hoped, may be induced to make a much more complete investigation.

In a fetus measuring 32.5 mm., no center had yet appeared for any of the vertebrae. (Although the estimated age according to Keibel and Mall is 9 weeks, it was aborted 49 hours after a single coitus.)

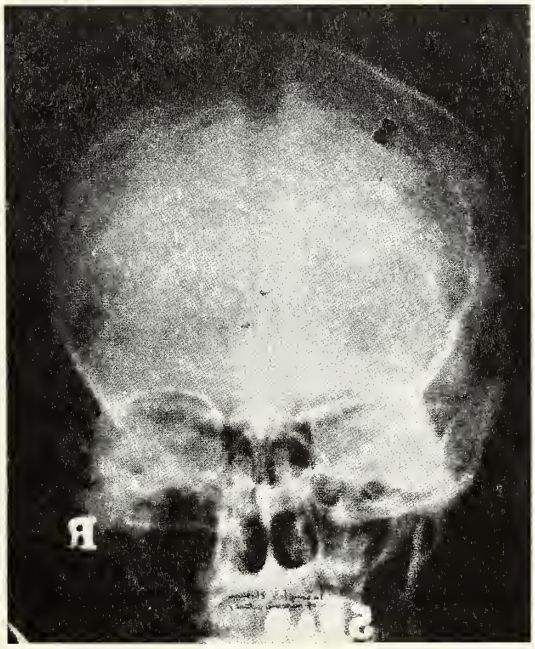

Fig. 6. Age twenty-seven. Incomplete closure of metopic suture.

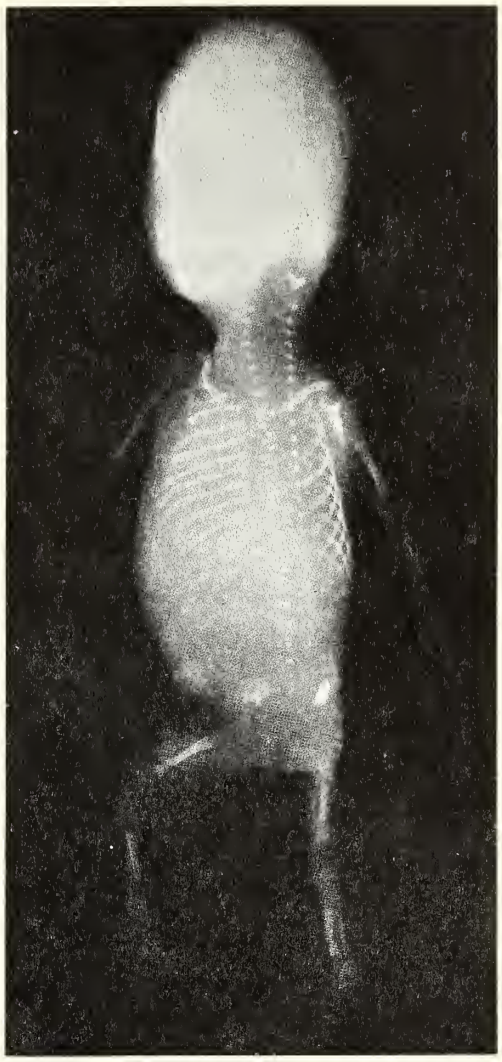

Fig. 7. Male, 70 mm. (12 weeks). Primary centers present for most long bones, scapula and ilium. Neural arches appear before vertebral bodies above, and after, below.

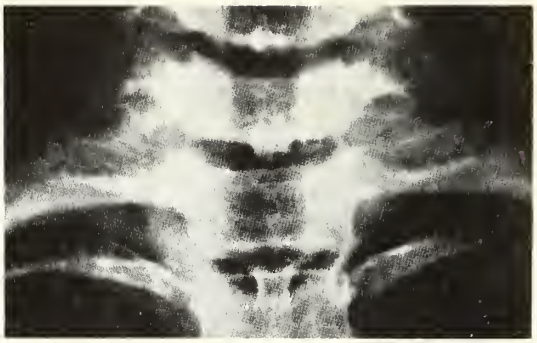

Fig. 8. Female, aged thirteen. Epiphyses for tips of transverse processes of first two thoracic vertebrae present on each side. (Courtesy of Dr. J. D. Camp, Rochester, Minnesota.)

CERVICAL VERTEBRAE

Although the seven primary centers for the neural arches were present in every fetus of 62 mm. in length ($11\frac{1}{2}$ weeks) or larger, no center had as yet appeared in a male fetus of 70 mm. (12 weeks) for any of the vertebral bodies, although that for the last cervical vertebra was already visible in a female fetus of 62 mm. ($11\frac{1}{2}$ weeks). Five pairs of centers of the lower five cervical vertebrae were noted in a male fetus of 109 mm. (15 weeks) and in a female of 125 mm. (16 weeks), while in another female of 175 mm. ($20\frac{1}{2}$ weeks) six were present. All larger specimens as well as a number of smaller ones, including a male of 147 mm. (18 weeks) and both male and female of 165 mm. (20 weeks) showed centers for all the cervical vertebral bodies. In the cervical region, the neural arches appear before the vertebral bodies, thus differing from the caudal extremity of the spine (see Fig. 7).

FUSION OF POSTERIOR ARCH OF ATLAS

In 2 girls aged 9 years and 1 month and 12 years and 1 month respectively, the arch of the atlas had not fused in the middle line posteriorly.

THORACIC AND LUMBAR VERTEBRAE

Primary centers for both bodies and neural arches were present for all thoracic and lumbar vertebrae in every fetus of 62 mm. ($11\frac{1}{2}$ weeks) or older.

UPPER AND LOWER EPIPHYSEAL PLATES FOR VERTEBRAL BODIES

These are best seen in the lateral view and are then most conspicuous forming a flattened triangular contour in front. In a girl aged 12 years and 5 months, such plates were noted in the thoracic region. In another girl aged 13 years and 5 months, they were noted upon the upper surfaces of the last thoracic and all five lumbar vertebrae and on the lower surfaces of the last two thoracic and first lumbar but not on the lower four lumbar vertebrae.

CENTERS FOR TRANSVERSE PROCESSES

In a boy aged 17 years and 7 months, secondary centers for the transverse processes of the last cervical were seen on both sides as well as those for the second thoracic on the right and the third thoracic on the left. They were not evident on the left of the second or the right of the third thoracic vertebra.

In a girl aged 13 years (see Fig. 8), centers for the extremities of the transverse processes of the first two thoracic vertebrae were noted. In a boy aged 14 years and 8 months, centers for the tips of the transverse processes of the first thoracic vertebra were likewise seen.

In a girl aged 13 years and 5 months, such epiphyses were seen on both sides of the first and third, and the right side of the fourth and left side of the fifth lumbar vertebra. They were not seen on either side of the second, the left side of the fourth nor the right side of the fifth lumbar vertebra.

Those of the first lumbar vertebra frequently persist throughout life as a separate ossicle, the homologue of the rib in the lumbar region.

PERSISTENT EPIPHYSES FOR THE VERTEBRAL PROCESSES

The persistence of epiphyses at the extremities of the transverse and spinous processes, and also over the upper and lower articular processes of the various vertebrae is important mainly because of their confusion with fractures, but so far

no exact study can be gleaned as to the period of their appearance.

CENTER FOR SACRALIZED LUMBAR VERTEBRA

This common anomaly is evidently produced by a separate center of ossification, for which the term lateral mass of lumbar vertebra is suggested to indicate that it is in series with the lateral mass of the sacrum below.

In a girl aged 3 years and 7 months (see Fig. 9), such an epiphysis is noted for the fifth lumbar vertebra on the left side, although none such is present on the right. It has not yet fused with the lumbar vertebra with which it is in contact, and has not yet reached the sacrum.

CENTERS FOR BODIES OF SACRAL VERTEBRAE

Unlike the cervical vertebrae, the primary centers for the bodies appear before those for the neural arches, those for the bodies of the first two segments being already present in the female fetus of 62 mm. ($11\frac{1}{2}$ weeks) and the male of 70 mm. (12 weeks), and although all five bodies were visible in the male of 90 mm. ($13\frac{1}{2}$ weeks),

Fig. 9. Female, aged three years seven months; center present for process of sacralized lumbar vertebra on the left but not on the right. (Courtesy of *Medical Journal of Australia.*)

Fig. 10. Male, aged seventeen years eight months. Note epiphyses on lateral aspects of lateral mass. (Courtesy of Dr. E. N. Cleaves, Boston, Massachusetts.)

there were but three only in the male of 109 mm. (15 weeks), four only in the male of 147 mm. (18 weeks), and the female of 233 mm. (26 weeks). The smallest female showing four centers measured 150 mm. ($18\frac{1}{2}$ weeks), and the smallest showing all five centers (see Fig. 11) was 165 mm. (20 weeks) in length. There is evidently a wide variation in the time of appearance of these centers.

CENTERS FOR NEURAL ARCHES OF SACRAL VERTEBRAE

The earliest appearance for the neural arches of the first sacral segment was seen in the female in a fetus of 62 mm. ($11\frac{1}{2}$ weeks) and in the male in a fetus of 109 mm. (15 weeks) and for the second segment in a male of 147 mm. (18 weeks). The earliest for the third and fourth segments were noted for a female 150 mm. ($18\frac{1}{2}$ weeks). and for a male 165 mm. (20 weeks) in length. The smallest male showing all five pairs of arches was 171 mm. ($20\frac{1}{2}$ weeks) in length and the smallest female 205 mm. (23 weeks). On the other hand, in considerably larger fetuses, up to 316 mm. (36 weeks) in a male and 298 mm. (34 weeks) in a female, the arches for the fifth segment had not yet appeared.

CENTERS FOR LATERAL MASSES OF SACRUM

The lateral masses of the sacrum are developed from three primary centers on each

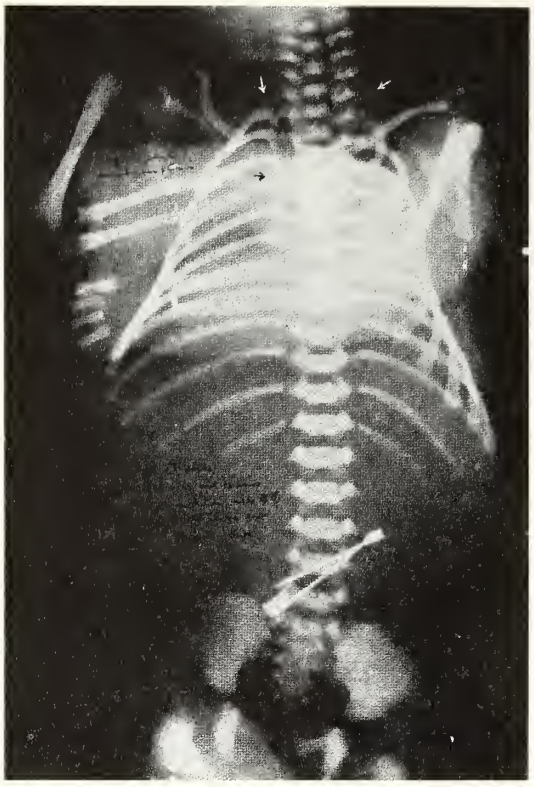

Fig. 11. Male, 275 mm. (31 weeks). Arrows point to cervical ribs on both sides and to manubrium sterni. Three other sternebrae present. Center and arches of five sacral segments as well as two centers for lateral masses on each side, also ilium, ischium and pubis present.

side. The centers for the first pair were noted earliest in a male fetus 180 mm. long (21 weeks) and in a female 220 mm. (25 weeks). The second pair (see Fig. 11) were seen in a female 220 mm. long (25 weeks), as well as in all larger specimens. The third pair were noted in the female of 220 mm. (25 weeks) on one side only and in a male of 312 mm. in length (33 weeks). They were not present, however, in a female of 315 mm. (36 weeks) nor in a male of 334 mm. (38 weeks).

In a girl aged 3 years and 7 months, the lateral mass had not yet fused upon either side.

EPIPHYSES OVER LATERAL ASPECTS OF SACRUM

Cleaves has studied in 16 American boys only by means of stereoscopic roentgenograms (Fig. 10) the epiphyseal plates situated on the lateral aspects of the sacrum, that is, over the parts formed by fusion of the three centers for the lateral masses and finds the incidence of their presence as follows: (a) representing the number of boys examined, (b) the number showing the presence of these epiphyses and (c) the number in whom such have been found to be fused (Table II).

Some of the boys have been submitted to repeated examinations up to four times per year. The youngest boy showing such center was aged less than 13, the same boy was also the youngest in whom they had fused at the age of 15. The oldest boy in whom the epiphysis had not yet appeared was aged 18 years and 2 months. In the former, an interval of but 2 years and 1 month intervened between the observed time of non-appearance of this epiphysis and the date of its fusion. The longest interval noted between the observed dates of unfused epiphysis is 2 years and 4 months so that the time of appearance is apparently a brief one, and it is present in the majority of boys at the age of 16, which is also the age of maximum incidence. Fusion apparently takes place in the majority of boys at the age of 18.

Table II

Ages	(a)	(b)	(c)
12	8	1	0
13	9	1	0
14	10	4	0
15	11	5	1
16	9	7	0
17	5	4	1
18	4	1	3
19	2	0	2

I have seen this epiphysis on each side in 2 girls aged 13 years and 8 months and 2 boys aged 14 years and 8 months, and 18 years and 2 months respectively.

COCCYX

The only center for the coccyx seen before birth was that for the body of the first segment. It was noted earliest in a female

fetus of 262 mm. (30 weeks) and in a male of 296 mm. (33 weeks), but not present in a female 324 mm. (37 weeks) nor in a male 334 mm. in length (38 weeks). After birth the rectal contents often obscure to a large extent a clear view of the coccyx, so that it is relatively infrequent to be certain which centers for this bone have appeared.

Although present in a female aged 8 months and in 3 males during the second and third years, in a girl aged 3 years and 7 months the first segment had not yet appeared. This latter is the same subject in whom a center for a sacralized lumbar vertebra was present, indicating an apparent cephalad shifting of the sacrococcygeal portion of the vertebral column.

In a boy aged 7 years and 4 months although the coccygeal cornu was already formed on the right side, upon the left it was represented by two distinct and detached ossific centers.

In a girl aged 5 years and 4 months and a boy aged 10 years and 7 months, the second segment had not yet appeared, while in a girl aged 10 years and 0 months and a boy aged 12 years and 0 months, centers were present for all four segments.

In a woman aged 23 years and 6 months, there was not yet any appearance of the center for the third segment. Of 16 females between the ages of 11 to 23 inclusive, this center was found in 14, although present in all of 19 males of the same age period.

The fourth coccygeal segment was not present in a woman aged 25 years and 7 months, nor in a man aged 27 years. Possibly its absence persists throughout adult life in some individuals. Of 22 females and 18 males between the ages of 11 and 25 (inclusive), this segment was missing in 9 females and 4 males.

CENTERS FOR STERNEBRAE

The several centers for the sternum are by no means as regular in their arrangement as are those of the vertebrae or of the ribs (see Fig. 11). The first three centers were noted earliest in a male fetus 180 mm. (21 weeks) in length; the earliest showing four centers was a male of 218 mm. (25 weeks). Five centers were present in a male fetus 283 mm. long (32 weeks), and the first to show six centers was a female 295 mm. in length (33 weeks).

RIBS

A fetus of 32.5 mm. expelled 49 days after a single coitus showed 10 pairs of ribs, although another of 30 mm. did not show any. All fetuses 62 mm. (11½ weeks) and longer possessed at least eleven pairs of ribs. However, although a female of 62 mm. as well as 29 other fetuses of 90 mm. (13½ weeks) or longer had all twelve pairs, there were 5, including a female 298 mm. (34 weeks) long and a male of 315 mm. (36 weeks), in which only eleven pairs were present.

CERVICAL RIBS

Cervical ribs were noted to be present in quite small fetuses (see Fig. 11), namely in a female of 165 mm. (20 weeks) and a male of 134 mm. (17 weeks).

Sir William Turner quotes Rosenmuller as having described a six months' fetus with a cervical rib.

UPPER LIMB

Primary centers for the clavicles, scapulae, humeri, radii, and ulnae were present in all fetuses of 32.5 mm. (49 days) and over (see Fig. 6). Those for the metacarpals and proximal and distal rows of phalanges were also present in all fetuses of 62 mm. (11½ weeks) and over (see Fig. 6). Those for the metacarpals and distal rows of phalanges were also present in all fetuses of 62 mm. (11½ weeks) and over.

PRIMARY CENTER FOR CLAVICLE

The clavicle was noted on each side as the sole center in a male fetus of 30 mm. in length (9 weeks) (see Fig. 12). Mall records its presence in a fetus of 15 mm. (6½ weeks) but it is possible that those shown by his peculiar clearing method may not be demonstrable by roentgen examination owing to insufficient calcification. The condition of craniocleidodysostosis evidently has its origin prior to the ninth week of fetal life.

EPIPHYSIS FOR CLAVICLE

The medial extremity of the clavicle was noted in 862 instances under the age of 30. The youngest female in whom an epiphysis was noted was aged 11 years and 7 months, and the youngest male 11 years and 8 months in whom it was present on the left side, the oldest being 25 years and 11 months in a female in whom it was present on the left but absent on the right and in a male, aged 25 years, on both sides. Stevenson states that it may be delayed until 28 years but of the 24 instances in individuals aged 27 to 29 no epiphyses were seen. At no age do more than 65 per cent of clavicles appear to be possessed with epiphyses, suggesting the possibility that the epiphyseal center for this bone is not a constant feature, but it must be remembered that such centers are frequently difficult to demonstrate, partly owing to the irregularity of the sternal extremity of the clavicle, and partly to a mixed background of intrathoracic structures, vertebrae and posterior parts of the ribs, while confusion with costotransverse and and costocentral articulations is likely to be encountered.

Fig. 12. Male, 30 mm. (nearly 9 weeks). Clavicles only bones ossified.

Table III illustrates the frequency of occurrence of such epiphyses. Columns (a) represent the number of clavicles examined, and (b) the number of epiphyses found in each sex in each age group respectively.

In Table III half of the females aged 17 and the majority of the males aged 19 and 21 years possess epiphyses for the sternal end of the clavicle, but the majority of both sexes at all other ages show absence of such epiphyses.

Table III

Age	Females		Males	
	(a)	(b)	(a)	(b)
11	15	2	5	2
12	15	0	11	1
13	6	2	15	0
14	8	2	11	2
15	17	4	11	1
16	19	4	16	1
17	20	10	20	7
18	11	9	20	3
19	36	14	14	8
20	41	16	23	7
21	26	11	26	17
22	20	5	19	7
23	23	4	20	5
24	26	4	30	2
25	26	2	27	2
26	12	1	12	0

PRIMARY CENTER FOR SCAPULA

This was noted in all fetuses of 32.5 mm. (49 days after single coitus) and over.

EPIPHYSIS FOR INFERIOR ANGLE OF SCAPULA

The epiphysis for the inferior angle of the scapula was clearly demonstrated in 3 subjects only, namely, 2 females aged 17 and 18 years and 11 months respectively in both of whom it was present in both sides (see Fig. 13) and in a male aged 16 years and 10 months. This center is evidently rarely seen, probably because this angle of the scapula is usually obscured by the lateral aspect of the bony cage of the chest, and also because this part of the bone is generally displayed lying in a sagittal direction.

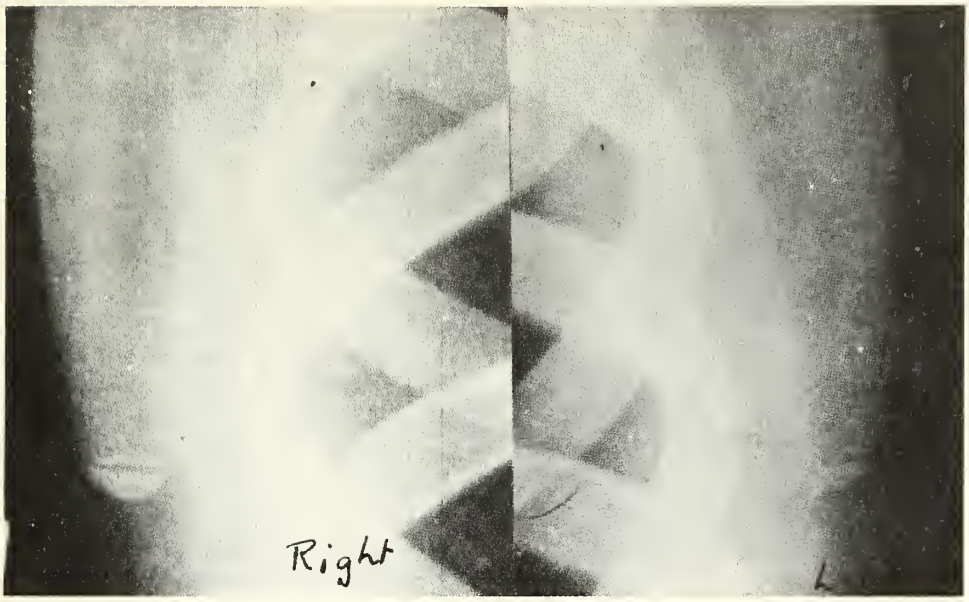

Fig. 13. Female, aged seventeen. Centers present for inferior angle of scapula on each side.

MAIN EPIPHYSIS FOR CORACOID PROCESS

Of 237 female and 263 male infants within 48 hours after birth, Menees and Holly found the center for the main part of the coracoid process in 32 instances (13.5 per cent) in the female and 28 (10.6 per cent) in the male.

Hill noted this epiphysis in only 1 each of 39 female and 69 male fetuses of an estimated age of 28 weeks. At full term, it was recorded in 7 of 45 females and 8 of 73 males.

In my series, the cartilaginous junction of the coracoid process with the body of the scapula was especially noted on both sides in a female infant aged 8 months and in 4 girls between the ages of 4 years and 2 months and 7 years and 6 months inclusive, when the arm was elevated above the horizontal (see Fig. 14). It was likewise seen in boys aged 5 years and 11 months and 10 years and 3 months respectively. Regular observations of this process are rendered difficult by the overshadowing of the coracoid by the spine of the scapula as well as by the clavicle and head of the

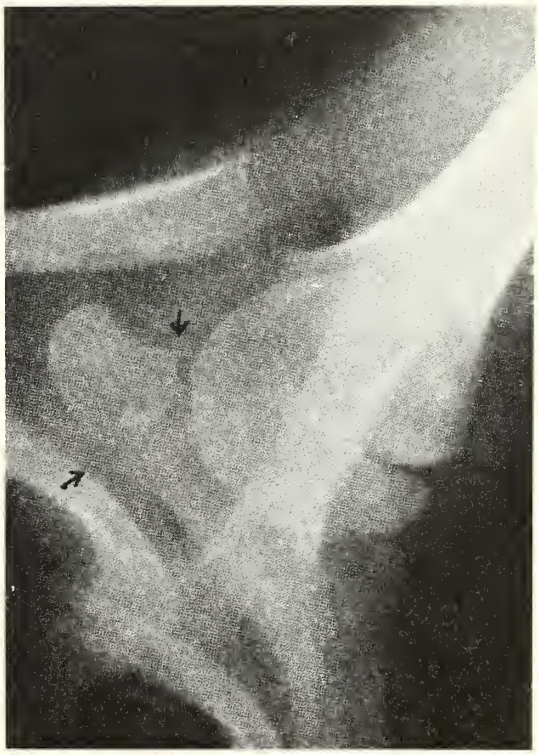

Fig. 14. Female, aged five. Showing center for main part of coracoid process.

Fig. 15. Male, aged fourteen years seven months. Epiphyses present for head and greater tubercle of humerus, acromion process, angle of coracoid and tip of coracoid.

humerus in the ordinary position of the shoulder with the arm adducted to the side.

EPIPHYSIS AT ANGLE OF CORACOID PROCESS

This epiphysis (see Fig. 15) is usually present at the junction of the ascending and horizontal rami on the medial aspect, where it forms a thin scale of bone. Table IV illustrates its incidence, columns (a) referring to the number of such processes examined and columns (b) the number of epiphyses found in each sex respectively.

The youngest instance where this was noted was a girl aged 10 years and 2 months, in whom it was present on the right side but absent on the left. This was the only epiphysis out of 71 instances in both sexes aged 10 to 12 inclusive, but examples were noted in a girl, aged 13 years and 7 months, on both sides and in a boy at the age of 14 years and 7 months. Of 295 instances (including 143 females and 152 males) aged 13 to 19 there were only 8 (5.6 per cent) in the female although there were 32 (21.0 per cent) in the male, suggesting a probability of greater frequency in the latter. In any case, the rarity of these centers makes it reasonably certain that the epiphysis is not a constant feature in the human subject. It would appear that in the female the appearance as well as the fusion with the ramus is earlier than in the male; thus of 83 females aged 17, 18, and 19, no epiphyses were seen, although 18 such were found present in the same number of males of the same age. The epiphysis was most frequently found in females at the age of 13 and in males at the age of 16. The oldest female with unfused epiphysis was aged 16, in whom it was present on both sides and the oldest male 19.

EPIPHYSIS AT TIP OF CORACOID

In boys aged 14 years and 7 months (see Fig. 15) and 15 years respectively, not only were the usual centers present for the angle of the coracoid and the acromial epiphysis, but there were additional centers for the tip of the coracoid. In another boy aged 16 a similar center for the tip of the coracoid was present as well as additional centers for the acromion process although that for the angle of the coracoid was absent.

Table IV

Age	Females		Males	
	(a)	(b)	(a)	(b)
13	8	4	19	0
14	9	1	16	2
15	17	1	16	5
16	26	2	18	7
17	33	0	25	6
18	11	0	32	11
19	39	0	26	1

EPIPHYSIS AT ACROMIAL MARGIN

The center for the posterolateral margin of the acromion process sometimes consists of two or more fragments and is often seen in the same roentgenogram showing the presence of the epiphysis for the angle of the coracoid (see Fig. 15). For clear demonstration, the roentgenogram should not be overexposed. Many views of the shoulder joint, even when clearly defining the various details of the joint itself, had to be excluded from consideration because of obliteration of detail of the acromion process with the result that a much smaller series was available for examination than in the case for instance of the coracoid process.

Table V illustrates its incidence, columns (a) representing the number of processes

examined, and columns (b) the number of epiphyses seen in each sex at each age group respectively.

The earliest appearances were in a girl aged 12 years and 0 months, in whom it was present on both sides and in a boy at the age of 14 years and 11 months. It was present in the majority of females at the age of 14 and of males at the age of 15 years, and was fused in all instances in females at the age of 17 and in the majority of males at the same age. While the oldest female with an epiphysis was aged 16 years and 1 month, the oldest male was aged 19 years and 2 months.

Table V

Ages	Females		Males	
	(a)	(b)	(a)	(b)
12	3	3	3	0
13	6	2	8	0
14	4	4	10	4
15	13	5	12	6
16	7	4	12	10
17	16	0	9	4
18	8	0	14	6
19	14	0	19	2

Again, it is by no means certain that a center always appears at the distal end of the acromion, for in 158 instances aged 12 to 19 (including 71 females and 87 males) there were but 50 (31.6 per cent) epiphyses (inclusive of 18 females and 32 males) noted.

PRIMARY CENTER FOR HUMERUS

This was found present in all fetuses in this series of 32 mm. (49 days after single coitus) or over (see Fig. 7).

EPIPHYSEAL CENTER FOR HEAD OF HUMERUS

Centers for the head of the humerus were found very much earlier than is indicated in the literature. Spencer, for instance, found it in the days long before roentgen rays were discovered, 9 times in 40 fetuses weighing 7 pounds or more. He could not find centers in 2 others weighing 10 pounds 12 ounces and 11 pounds 4½ ounces respectively.

Fig. 16. Female, 294 mm. (33 weeks). Note center for head of humerus.

However, in the present series, centers were quite clearly distinguished in a female fetus of 294 mm. (33 weeks) (see Fig. 16) and in a male of 295 mm. (33 weeks). As out of 10 fetuses of 294 mm. (33 weeks) and larger, 6 showed the presence of this epiphysis, it seems probable that the frequency of appearance of this center before birth has been considerably underestimated and this center ranks next in order of appearance to that of the distal femoral epiphysis and proximal tibial epiphysis.

Hill recorded this center present in 1 each of 26 female and 36 male fetuses of estimated age of 32 weeks and in 12 of 35 female and 11 of 49 male full term fetuses.

Menees and Holly found that of 237 females and 263 males within 2 days after birth, the center was present in 112 females (47.2 per cent) and 122 males (46.4 per cent).

Of 40 instances in babies during their first year, the oldest without epiphyseal center was a girl aged 1 month and a boy aged 6 months. The earliest centers noted were 2 months in each sex. All older children showed the presence of this epiphysis.

Fig. 17. Male, aged one year three months. Head of humerus is distinct from that for greater tubercle.

EPIPHYSIS FOR GREATER TUBERCLE OF THE HUMERUS

Many roentgenologists, notably Cohn, have doubted the existence of a separate center of ossification for the greater tubercle, and are of the opinion that this process is developed from extension of the center for the head over the lateral aspect of the diaphysis, but in numerous instances in young children (see Fig. 17), each center has been noted side by side, one for the head lying on the inclined plane on the medial aspect and the other on another inclined plane on the lateral side of the upper aspect of the diaphysis. Unfortunately in many instances, the head of the humerus is obscured by the overhanging acromion process or even by the coracoid, so that it is frequently difficult to define the center for the greater tubercle and to separate it from the head proper. Borovansky and Hnévkovský give very good diagrams illustrating the appearance of the head and greater tubercle in boys of Prague at various ages from 4 years and 1 month up to 14 years and 7 months.

The incidence of appearance of this epiphysis is represented by Table VI. Columns (a) represent the number of humeri examined and columns (b) the number of epiphyses noted at each age in each sex respectively.

Table VI

Age	Females		Males	
	(a)	(b)	(a)	(b)
Under 1	8	4	15	8
1	9	7	16	3
2	7	7	11	7
3	10	7	8	6
4	7	3	7	6
5	9	4	12	3
6	13	3	4	2

During the first year after birth, the earliest epiphysis for the greater tubercle was noted at 8 months in a girl and 6 months in a boy. Its absence was also noted at 11 months in a female while it was present in all 7 instances in females aged 2. In a boy aged 9 months, it was present on the left but not on the right side. Half of the epiphyses were noted present in girls during the first year and in the majority of boys during the third year. Paterson reports the appearance of this center at the end of the second or beginning of the third year, practically a year later than the above series of observations seem to show. Most other anatomists give 2 to 3 years.

FUSION OF EPIPHYSEAL CENTERS FOR GREATER TUBERCLE AND HEAD OF HUMERUS

After the first 2 years or earlier, the center for the greater tubercle overlaps that for the head of the bone, the two later fusing to form a conjoint epiphysis (see Fig. 18). The earliest instance of such fusion is seen in a girl aged 3 years and 7 months (both sides), but that for boys is not apparent from the above table. The

latest to fuse were in a girl aged 6 and a boy aged 6 years and 6 months, the majority fusing at the age of 4 in girls and 5 in boys. In all children over 6, including 43 aged 7 to 9, these two epiphyses had fused, but Davies and Parsons report an instance of non-fusion at the age of 12. In a boy aged 9 (not included in this series), the subject of craniocleidodysostosis, these epiphyses had not yet fused.

EPIPHYSIS FOR LESSER TUBERCLE OF HUMERUS

Like other roentgenologists, I have failed to find a single example showing the presence of this center, and doubts have been raised concerning its existence. However, the position of the lesser tubercle in front of the bone would certainly make such a center, even if it were present, much more difficult to demonstrate, especially as it is usually impossible to secure a good lateral view of this portion of the limb. Practically all anatomists describe the presence of this epiphysis.

FUSION OF UPPER CONJOINT EPIPHYSIS WITH DIAPHYSIS OF HUMERUS

The incidence of fusion of the upper conjoint epiphysis of the humerus is represented by Table VII. Columns (a) show the

Table VII

Age	Females		Males	
	(a)	(b)	(a)	(b)
15	11	1	17	0
16	10	3	17	1
17	25	15	21	3
18	9	8	6	4
19	27	22	23	17
20	24	22	14	14

number of humeri examined and columns (b) the number of instances in which such centers have been found fused at each age in each sex respectively.

From the figures in Table VII, it seems that the age of fusion of the conjoint epiphysis for the head and the greater

Fig. 18. Age four years. Commencing union of epiphyses for head and greater tubercle of humerus, forming socket into which fits as a cap conical upper extremity of diaphysis.

tubercle with the diaphysis is fairly constant, much more so than is the case with the great majority of other epiphyses. The earliest fusion was at the age of 15 years and 8 months in a girl and 16 in a boy, the latest 20 years and 5 months in a female (both sides), and 19 years and 2 months in a male. The majority were fused at the age of 17 in females and 18 in males. Union was constantly found at 21 in females and 20 in males, which fact does not at all correspond to the various ages, 20 to 25 given by numerous anatomists, and also which differs appreciably from the ages given by Paterson, namely 18 for females and 21 for females.

EPIPHYSIS FOR LATERAL EPICONDYLE

Table VIII records the incidence of the epiphysis for the lateral epicondyle, columns (a) referring to the number of elbows examined, columns (b) the number of epiphyses present at each age in each sex respectively.

The earliest centers observed for this epiphysis were in a girl aged 8 years and 6 months and in a boy aged 10 years and 7 months. At the age of 11 in females and 12 in males, this epiphysis was found present in the majority of instances, while the oldest subjects with unfused epiphyses were aged 16 in each sex (both sides in a female).

Table VIII

Age	Females		Males	
	(a)	(b)	(a)	(b)
8	13	2	18	0
9	6	2	17	0
10	6	2	19	3
11	7	6	11	4
12	1	1	23	15
13	8	4	16	12
14	8	1	18	14
15	8	0	12	8
16	6	2	11	1

Despite the opinions of Cohn and Paterson, this epiphysis is probably present, like those of the capitulum, trochlea and medial epicondyle in every case at some period between the ages of 7 and 17 years. In the female, it was present in 11 instances out of 16 (69 per cent) between the ages of 11 and 13, and in the male in 41 of 57 instances (72 per cent) aged 12 to 14, or 26 of 34 instances (76 per cent) aged 13 and 14. The case figured by Paterson, which is described as an extension of the capitular epiphysis and which is stated to occur in 30 per cent of cases is certainly a fusion of the capitulum with the lateral epicondyle, which always takes place before union of the conjoint epiphysis with the diaphysis.

CENTER FOR CAPITULUM

This center had not yet appeared in a female infant aged 2 months nor in males aged 1 week, 1, 2, 8 and 9 months respectively, but was noted on both sides in a girl aged 9 months and in a boy aged 11 months as well as in all older children, including 31 instances in children aged 1 year, 35 aged 2 and 27 aged 3. Davies and Parsons report its absence in one instance at 18 months (sex not stated).

TROCHLEAR EPIPHYSIS

Table IX represents the incidence of the epiphysis for the trochlear surface of the humerus, columns (a) referring to the number of elbows examined, and columns (b) the number of epiphyses found at each age period and in each sex respectively.

The earliest centers for the trochlea were noted at the age of 7 years in a girl and 8 years and 9 months (both sides) in a boy, while the majority of girls aged 9 and half of the boys aged 10 showed the presence of this center. The epiphyses were still evident in a girl aged 16 as well as in a boy of the same age.

UNION OF EPIPHYSES OF LATERAL EPICONDYLE, CAPITULUM AND TROCHLEA

It is usual to describe the union of the epiphyses of the lateral epicondyle and trochlea on each side of the capitulum (Fig. 19) to form a new conjoint epiphysis which fuses at a later date with the diaphysis. From a roentgenological study of this series, this method of development appears to be correct, and there is no valid reason for the supposition, as suggested by Paterson, that in some 30 per cent of cases the lateral epicondyle is formed by extension from the capitulum. If this were the case, one would expect to find intermediate stages of this extension, such as may be observed in the spinous process developed from the primary center for the scapula, or the main part of the olecranon process from the shaft of the ulna, but such intermediate stages are not seen. On the contrary, the

Table IX

Age	Females		Males	
	(a)	(b)	(a)	(b)
7	8	1	15	0
8	14	4	20	4
9	6	5	17	5
10	7	5	18	9
11	7	6	12	8
12	2	2	23	21
13	8	4	17	14
14	8	1	21	18
15	8	0	14	11
16	4	2	10	1

adjacent margins of the epiphyses for the lateral epicondyle and capitulum prior to fusion are always smooth and well defined.

In Table x, columns (a) show the number

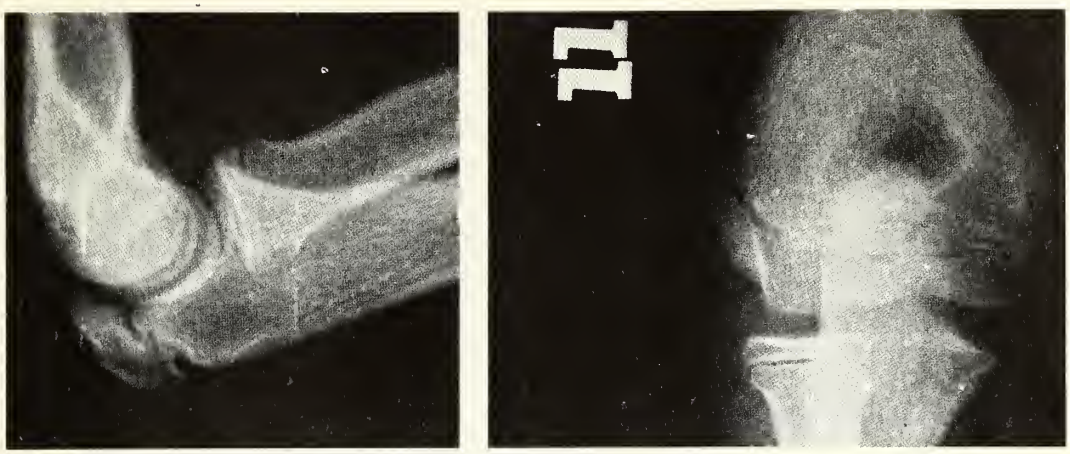

Fig. 19. Male, aged fifteen. Epiphysis of lateral epicondyle, capitulum and trochlea unite to each other, before joining diaphysis. Epiphysis for medial epicondyle distinct.

of instances in which these three epiphyses were present, and columns (b) the number of those fused to each other at each age group in each sex respectively.

The union of the lateral epicondyle and trochlea on each side of the capitulum is almost simultaneous, although the former is sometimes slightly later than the latter. The lateral edge of the trochlea is generally narrow and often ill defined, in marked contrast to the smooth surfaces of the capitulum and lateral epicondyle. In fact, the latter is somewhat discoidal in shape and sometimes appears to belong to the capitulum rather than to the shaft of the bone. In a boy aged 14 years and 7 months, the capitulum on each side had fused with the lateral epicondyle, but the adjacent very narrow edges of the trochlea and capitulum were still ununited.

Table X

Age	Females		Males	
	(a)	(b)	(a)	(b)
8	2	0	0	0
9	2	0	0	0
10	1	1	2	0
11	5	1	3	0
12	1	0	15	2
13	4	1	12	4
14	1	0	13	9
15	0	0	9	1
16	2	0	1	1

In a girl aged 10, the three epiphyses were fused with each other, but the earliest instance in a boy was at the age of 12, in whom they were all united on both sides. Union had taken place in the majority of the boys at the age of 14, but had not occurred in a girl aged 16 nor in a boy aged 15, in each case on neither side.

Table XI

Age	Females (Author)		Males (Author)		Males (Sidhom and Derry)	
	(a)	(b)	(a)	(b)	(a)	(b)
13	8	4	19	0		
14	8	5	22	2	91	32
15	8	8	15	4	43	33
16	6	5	10	9	95	88

FUSION OF CONJOINT DISTAL EPIPHYSIS WITH DIAPHYSIS OF HUMERUS

Table XI indicates the incidence of union of the fused distal epiphyses with the diaphysis of the humerus, columns (a) representing the number of such epiphyses examined and columns (b) the number fused at each age, in each sex, in the present series

as well as in a similar series of boys investigated by Sidhom and Derry in Egypt.

The earliest age of which union occurred was 13 years and 4 months in a girl and 14 years and 7 months in a boy. Fusion was present at the age of 13 in half of the girls and 16 in the majority of boys, but instances of non-fusion were noted at the age of 16 in both sexes (on both sides in a female). Sidhom and Derry found the majority among a larger series of Egyptian boys fused at the age of 15, that is a year earlier than in the Australian series, for while in 33 of 43 boys in Egypt, fusion had taken place, in Australia only 4 of 15 instances at the same age showed union.

Table XII

Age	Females				Males			
	Australian		Hindu		Australian		Egyptian	
	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)
2	13	1			18	0		
3	6	2			16	0		
4	5	2			19	0		
5	20	17			15	7		
6	8	7			14	5		
7	9	9			17	4		
10	7	4			19	19		
11	4	3			13	13		
12	1	1			21	19		
13	8	5	7	0	16	15		
14	8	3	24	6	19	18	101	95
15	8	0	16	1	16	16	39	29
16	6	3	12	2	10	5	98	41
17	5	0	16	0	18	7	95	15
18	5	0	9	0	10	0	68	6
19	6	0	3	0	11	0	24	1

EPIPHYSIS FOR MEDIAL EPICONDYLE

The medial epicondyle (Fig. 20), unlike the lateral, is altogether separated from the other centers at the lower end of the humerus and fuses directly and independently with the diaphysis.

Table XII shows the incidence of this epiphysis, columns (a) being the number of elbows examined and columns (b) the number of instances in which the epiphyses were present in Australian girls of my series and Hindu girls of Galstaun's series and in Australian boys of my series and Egyptian boys of the series of Sidhom and Derry respectively.

The earliest age at which this epiphysis has been noted is 2 years and 2 months in a female and 5 years and 5 months in a male. This center was found in the great majority of girls at the age of 5 and of boys at the age of 7. Its absence was noted in a girl aged 6 and in a boy aged 7 years and 3 months.

The youngest girls in whom the medial epicondyle was found fused with the diaphysis were aged 10, the youngest boys 12, in 1 case being present on the right although fused on the left side. In one-half of the girls, union had taken place at the age of 14 and in one-half of the boys at 16. The center was found still unfused in a girl aged 16 years (both sides) and in a boy aged 17 years. Paterson gives the date of union as 18 to 21 in males, but in this series, in every one of 36 instances in males at these ages it was already fused, although there were 7 in Sidhom and Derry's series,

Fig. 20. Female, aged eight. Centers for medial epicondyle, capitulum and head of radius present, but not trochlea, lateral epicondyle nor tip of olecranon.

that is 6 of 68 aged 18, and 1 of 24 aged 19, the oldest aged 19 years and 3 months with unfused epiphysis.

According to the investigations of Galstaun, it would appear that fusion does not take place earlier in Hindu than in Australian girls.

PRIMARY CENTERS FOR RADIUS AND ULNA

In all fetuses measuring 32.5 mm. (49 days) or longer, the primary centers for both the radius and the ulna had already appeared (see Fig. 7).

EPIPHYSIS FOR THE TIP OF THE OLECRANON PROCESS

The main part of the olecranon process is formed by an extension upward from the diaphysis, a small wedge, including the tip alone being formed from a separate center (Fig. 20), which may or may not comprise part of the articular surface of the greater semilunar notch. Generally there is only one center, but more often there are two or more.

Table XIII represents the incidence of this epiphysis, columns (a) representing the number of elbows examined and columns (b) the number of epiphyses present in girls in my series and Galstaun's series and also in my series of boys respectively.

The youngest subjects in whom epiphyses were present were a girl aged 6 and a boy aged 7. From the above it would appear that the epiphysis is present in a majority of girls at the age of 8 and of boys at the age of 10. While fusion takes place in the majority of girls at the age of 14, union does not occur in the majority of boys until 16 years of age. Instances of non-fusion were noted in a female at the age of 16 years

Table XIII

Age	Females				Males	
	Australian		Hindu		Australian	
	(a)	(b)	(a)	(b)	(a)	(b)
6	9	1			21	0
7	10	1			19	1
8	14	8			22	3
9	5	5			17	3
10	7	3			19	15
11	6	6			23	9
12	2	2			27	26
13	7	5	7	7	16	15
14	8	1	24	14	22	21
15	8	0	16	2	18	16
16	5	3	12	0	5	2

and in a male at 17 years and 6 months. The epiphyses had not yet appeared on either side in girls aged 10, but examples of ab-

TABLE XIV

Age	Females				Males			
	Australian		Hindu		Australian		Egyptian	
	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)
3	7	2			20	1		
4	10	5			20	8		
5	22	13			16	10		
6	9	7			23	15		
7	11	11			23	19		
8	21	21			27	26		
13	10	7	7	7	18	18		
14	13	4	24	7	24	23	99	91
15	7	1	16	3	20	18	41	28
16	7	2	12	1	11	5	98	35
17	3	0	16	2	22	11	94	11
18	5	0	9	1	10	0	67	5
19	7	2			11	0		
20	4	0			15	1		

sence, whether of non-appearance or fusion, can be noted at all ages in boys. The earliest to fuse was in a girl aged 13 years and 10 months.

PROXIMAL EPIPHYSIS OF THE RADIUS

Table XIV represents the incidence of this epiphysis, columns (a) and (b) having the same significance as the corresponding columns in the table for the medial epiphysis.

The earliest epiphysis noted was in a girl aged 3 years and 4 months and in a boy also aged 3 years and 4 months. Davies and Parsons noted an instance in a girl aged 2. Half of the females aged 4 and the majority of males aged 5 showed the presence of this epiphysis. It was absent in girls aged 6 and in a boy aged 8.

The earliest age at which fusion had occurred was 13 years and 10 months in a girl and 14 in a boy. Union had occurred in the majority of females at the age of 14 and of males at 16. One woman aged 19 years and 10 months showed non-fusion on both sides, while bilateral non-fusion was also noted in a male aged 20 years and 5 months.

Sidhom and Derry found the epiphyses of the majority of Egyptian boys fused at the age of 16 as above. In one instance it was not fused at the age of 18 years and 6 months.

TUBERCLE OF RADIUS

In no instance has a separate epiphyseal center for the bicipital tubercle of the radius, as described by Frazer, been found.

DISTAL EPIPHYSIS OF RADIUS

Table XV represents the observed incidence of appearance of this epiphysis, columns (a) showing the number of wrists examined and columns (b) the number of centers present in girls of (i) my Australian, (ii) Pryor's American and (iii) Galstaun's Hindu series as well as the boys in (iv) my Australian, (v) Pryor's American and (vi) Sidhom and Derry's Egyptian series in each age group respectively.

The youngest female in whom this center was seen was aged 9 months, but it was not seen in any of 5 boys in their first year. A girl aged 1 year and 2 months showed no epiphysis on either side while a boy aged 1 year and 7 months old likewise showed no center, although present in 6 other instances in boys in their second year, the youngest being 1 year and 1 month. Cohn states that

this epiphysis is constantly present at the age of 6 months, yet in 3 males, aged 10 months, 11 months and 1 year respectively, this was not the case. The center was found in all of 22 instances of both sexes aged 2.

The youngest female in whom fusion had occurred was aged 15 years and 11 months, the youngest male 17 years and 3 months. The majority of females aged 18 and of males aged 19 showed union with the shafts. The oldest subjects in whom union was not complete were a female aged 20 years and 5 months and a male aged 23.

In the Australian series, the great majority were fused in the case of the girls at the age of 18 (in the Hindu series not until 19), and in boys at the age of 19 as in the Egyptian series of Sidhom and Derry. In 8 of the latter series, union had occurred at the age of 16. Like Galstaun, Pryor found union in American females at 19 and males at 20, that is, later than in both the Australian and the Egyptian series.

DISTAL EPIPHYSIS OF ULNA

Table XVI represents the observed incidence of appearance of this epiphysis, the grouping being the same as that of the preceding distal epiphysis of the radius.

The center for this epiphysis was first seen at the age of 5 in a girl and 5 years and 4 months in a boy. Paterson reports it present in a girl aged 4. The epiphysis was found in the majority of girls at the age of 5 and half of the boys at the age of 6. The oldest girl in whom it was found absent was aged 7, and the oldest boy 8 years and 6 months.

The youngest female in whom this center had fused was aged 15 years, the youngest male 17 years and 3 months. It will be noted that while the majority of epiphyses had fused at the age of 17 in females, it was not until the age of 19 that union was present in the majority of males. The oldest female in whom this center had not yet fused was aged 22 and the oldest male 23. Paterson's conclusion that "it joins the shaft at the same time as the radius, namely at 21 in the male and a year earlier in females," implies a considerably later date of fusion, that is at least two years later than is the case with the majority of the series of Australian, Egyptian and American subjects. It is true, however, that fusion of the lower epiphyses with the diaphyses of the radius and ulna are practically simultaneous.

The remarks made with reference to the lower end of the radius apply as well to the lower end of the ulna, thus it would appear

Table XV

Age	Females						Males					
	(i)		(ii)		(iii)		(iv)		(v)		(vi)	
	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)
0	3	3					5	0				
1	12	9					7	6				
14	8	8	14	14	24	22	49	49	2	2	104	104
15	7	6	6	6	16	12	48	48	3	3	41	41
16	14	10	12	12	12	8	44	44	4	4	99	91
17	12	7	17	11	16	11	41	40	14	13	90	74
18	16	3	7	4	9	5	42	35	12	12	70	36
19	6	1	10	4	3	1	32	12	8	6	23	7
20	8	1	6	0			21	6	6	1		
21	5	0	1	0			30	6	2	0		
22	7	0	2	0			22	0	5	0		
23	11	0					20	1				

Table XVI

Age	Females						Males					
	(i)		(ii)		(iii)		(iv)		(v)		(vi)	
	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)
5	3	2					11	4				
6	9	6					12	6				
7	7	6					27	16				
8	14	14					16	11				
14	8	8	14	14	24	23	49	49	2	2	104	104
15	7	5	6	6	16	13	48	48	3	3	41	40
16	13	9	12	12	12	8	43	43	4	4	94	85
17	11	5	17	11	16	12	37	36	14	13	87	61
18	16	3	7	4	9	5	40	32	12	10	69	33
19	6	0	10	4	3	2	31	9	8	1	24	6
20	9	1	6	0			19	3	6	0		
21	5	0	1	0			30	4	2	0		
22	8	1	2	0			22	0	5	0		
23	11	0					18	1				

that, in Galstaun's Hindu series, with the exception of a few instances, fusion does not take place generally at an earlier age than in this Australian series of European descent. Sidhom and Derry found that the majority of Egyptian males aged 18 show fusion, that is a year earlier than in the Australian series. In one boy in their series, fusion was present at the age of 15 years and 11 months. Pryor found union in the majority of American girls at 16 and of boys at 19, in the former case earlier than in the Australian series, although the boys are later than in the Egyptian series.

EPIPHYSIS FOR STYLOID PROCESS OF ULNA

Borovansky and Hnévkovský found a separate epiphysis for this process in a boy aged 5 years and 10 months, on both sides. They report 2 instances of this epiphysis, one of which is illustrated.

In a boy aged 13 years and 10 months, a separate ossicle representing the detached styloid process of the ulna is seen. This does not appear to have been caused by injury. In view of the frequency with which the styloid process is detached by trauma, it is important to recognize that this process may exist separately and independently as a separate ossicle.

CARPAL BONES

None of the carpal bones were seen in any fetus of my series, and no record of such has been discovered in the literature. With the possible exceptions of the capitate, and less frequently of the hamate, these ossicles probably never appear before birth.

Each of these as a rule is developed from a single center. Woollard states that two centers have been found for the navicular. Pfitzner has described a double center for the triquetrum, while Quain reports two centers being sometimes found for the lunate. Adair and Scammon report double centers for the capitate. In this series, double centers for the multangulum minus were noted in a girl aged 6, on the right side, but not on the left (see Fig. 21). Borovansky and Hnévkovský found these present on both sides in a boy aged 5 years and 10 months.

The order of appearance is by no means constant, for even in the same individual it may be different on each side, Thus (see Fig. 3), in a boy aged 6 years and 11

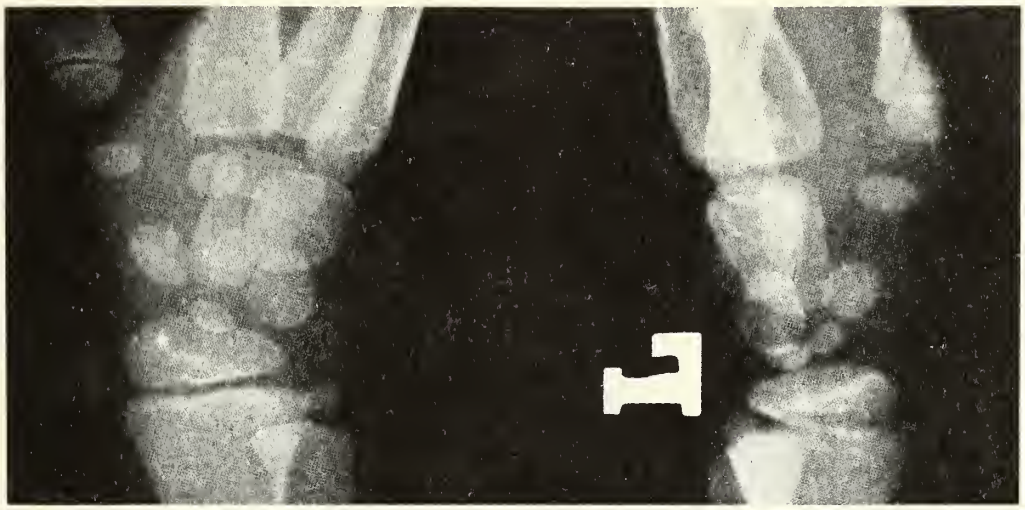

Fig. 21. Female, aged six. Two centers present for lunate, one palmar and one dorsal.

months, the multangulum majus was well marked on the left, but completely absent on the right; the lunate had just appeared on the right side, although no trace could be observed on the left. Pryor states that the order of appearance is a peculiarity of the family.

The first carpal bone to appear is usually the capitate, shortly followed by the hamate. Then follow the triquetrum, multangulum minus, lunate, multangulum majus, navicular and invariably last of all at a considerably later date, the pisiform, but there is considerable variation in the respective order of appearance of the lunate, multangula majus et minus and the navicular. In a female aged 3 months and a male aged 7 months Pryor noted the appearance of the hamate before the capitate.

NAVICULAR

Table XVII represents the incidence of appearance of the navicular bone, columns (a) showing the number of wrists examined and (b) the number of instances where centers have been found in each sex at each age group in my Australian series and in the American series of Pryor respectively.

The earliest centers noted were in a girl aged 4 years and 10 months and in a boy aged 4 years and 6 months. It was present in the majority of girls at the age of 4 and in half of the boys at the age of 5. The oldest subjects showing absence of centers were a

Table XVII

Age	Females				Males			
	Author		Pryor		Author		Pryor	
	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)
3	6	0	9	1	13	0	3	1
4	3	3	14	7	6	1	14	1
5	3	2	30	19	12	6	39	8
6	9	9	35	30	11	9	42	20
7	8	8	14	14	26	22	10	9
8	14	14	4	4	16	15	8	6

girl aged 5 years and 5 months and a boy aged 8. Woollard states that two centers have been found for the navicular. This is of special interest in consideration of possible fractures of this bone.

Pryor found this center in a girl aged 3 years and 6 months and in a boy aged 4 years and 4 months. In his series, it was not present in a girl aged 6 years and 4 months nor in a boy aged 8 years and 3 months. His series showed the center to be present in a girl aged 4 years and 4 months, but not present in another girl aged 6 years and 4 months nor in a boy aged 8 years and 3 months, the center being found in half of the girls at the age of 4 and in the majority of boys not until the age of 7, the latter being considerably later than among the Australians.

Table XVIII

Age	Females				Males			
	Author		Pryor		Author		Pryor	
	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)
1	9	0	3	0	5	1		
2	9	3	4	1	11	2	2	0
3	6	2	9	5	10	6	3	0
4	3	3	14	13	7	5	14	10
5	3	3	30	26	13	11	39	31
6	9	9	35	30	11	9	42	20

LUNATE

Table XVIII represents the incidence of the lunate, the arrangement being the same as for the navicular in the same series of individuals.

This center sometimes appears before the triquetrum and sometimes afterwards. The youngest subjects showing this center were a boy in his second year and a girl aged 2 years and 7 months. It was found present in all girls aged 4 or over and the majority of the instances of boys aged 3. Its absence was noted in a girl aged 3 years and 5 months, in one instance on both sides, and in a boy aged 6 years and 11 months, in whom it was present on the opposite side. On one side, it was the only carpal bone absent except the pisiform.

Pryor found this center in the majority of girls aged 3 and of boys aged 4. In his series it was absent in a girl aged 6 years and 3 months.

In a girl aged 6 (see Fig. 21), and boys aged 4 years and 7 months, 5 years and 7 months and 8 years respectively, two centers, one dorsal to the other, were noted for this bone. Pryor had noted on both sides in a boy aged 6 years and 4 months both the triquetrum and lunate to be possessed of double centers.

OS HYPERLUNATUM

A small center immediately alongside the lunate on the ulnar side is figured by Borovansky and Hnévkovský, under the title "hyperlunatum?".

TRIQUETRUM

Table XIX represents in the same manner as the preceding, the incidence of the triquetrum.

This center is usually the earliest of the carpal bones to appear after the capitate and hamate, but may be preceded by the lunate. The earliest centers were noted in a female at the age of 1 year and 5 months and in a male at the age of 2 years and 3 months. It was found in the majority of boys aged 3 and in all girls aged 4 or over. Its absence was noted in girls at the age of 3 and in a boy aged 7 years and 3 months, in whom it was present on the left but not on the right side.

TABLE XIX

Age	Females				Males			
	Author		Pryor		Author		Pryor	
	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)
1	11	6	3	1	3	0	2	1
2	10	1	4	3	11	4	2	0
3	7	3	9	9	13	7	3	2
4	3	3	14	14	7	6	14	11
5	3	3	30	30	13	13	39	36
6	9	9			11	11		
7	7	9			25	24		

PISIFORM

Table XX represents in the same manner as the preceding the incidence of the pisiform, and in addition columns (c) show the percentage incidence of the number of centers present as well as the incidence estimated by Paterson.

The youngest girl noted in this series with such a center was aged 7 years and 2 months and the youngest boys 7. It was present in the majority of girls at the age of 10 and in the majority of boys at 11. The oldest girl in whom it was not present was aged 10 years and 8 months and the oldest boy 14 years and 7 months.

The percentages at each age are compared with the figures given by Paterson, the latter appearing to be a rough estimate only and applicable to both sexes. In females it was present in each of 44 instances at the ages of 11 to 14, that is in 100 per cent. Thus, in this series, this bone was rather more frequently demonstrated than is estimated by Paterson, up to the age of 14 in boys and is present in all girls of the same age groups.

HAMATE

Hill has noted this center in 2 female fetuses of 36 weeks' gestation.

Except for the capitate, this is usually the first carpal bone to appear and was present in all babies of 9 months of both sexes and older, but was not present (on either side) in an infant aged 6 months, nor in male infants 1 week and 2 months old respectively. It was present in all 5 instances in babies aged 9 to 11 months. Davies and Parsons found it absent in a child aged 1 year and 3 months.

TABLE XX

Age	Females						Males					
	Author			Pryor			Author			Pryor		Paterson
	(a)	(b)	(c)	(a)	(b)	(c)	(a)	(b)	(c)	(a)	(b)	(c)
7	7	1		14	1		28	2		11	0	
8	10	4		8	2		17	0		9	0	
9	7	3		4	2		9	1		8	0	
10	8	6		5	4		8	2		6	0	
11	7	7	100%	3	3	100%	14	9	57%	5	1	25%
12	16	16	100%	2	2	100%	24	16	66%	5	2	55%
13	12	12	100%				40	30	75%	3	2	80%
14	9	9	100%				50	42	84%	1	0	100%

Of 237 instances in the female and 263 in the male, within forty-eight hours after birth, Menees and Holly found this bone present 28 times (11.8 per cent) in females and 11 times (4.1 per cent) in males. The hamate was present alone (without capitate) 7 times. Adair and Scammon found it present in 5 of 45 females within 48 hours after birth.

Adair and Scammon report double centers for this bone in a female newborn of 289 days' gestation and a male newborn of 267 days' gestation.

CAPITATE

Hill has noted this center in a female fetus of 36 weeks' gestation.

The capitate is usually the first carpal bone to appear. Pryor found it present in a male child aged 2 days, and in a female aged 4 days, and from the size of these concluded that they must have been actually present before birth. However, he found the center absent in a female aged 3 months and in a male aged 7 months, although the hamate was present in each case, but it is unusual for the hamate to precede the capitate. I have noted the absence of all carpals in a male aged 1 week, but this bone was present in every instance examined of babies of 2 months and older.

Of 237 instances in the female and 263 in the male, within 48 hours after birth, Menees and Holly found this bone present in the female 31 times (13.0 per cent) and 10 times (3.8 per cent) in the male, so that its frequency does not differ very much from that of the hamate. The capitate was present alone (without the hamate) 9 times. Adair and Scammon found it present in 6 of 45 females and 9 of 55 males within 48 hours of birth.

MULTANGULUM MINUS

Table XXI represents in the same manner as those for the navicular, lunate and triquetrum, the incidence of the multangulum minus in the same series of individuals.

Table XXI

Age	Females				Males			
	Author		Pryor		Author		Pryor	
	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)
3	6	1	9	1	11	2	3	0
4	3	2	14	7	7	1	14	0
5	5	5	30	24	10	4	39	9
6	9	9	33	28	10	7	41	18
7	7	7	14	14	29	26	10	7
8	12	12	4	4	15	14	8	7

The youngest girl showing this center was aged 3 years and 5 months, it being present on the right side, but absent on the left, and the youngest boy was aged 3 years and 10 months, in whom it was present on both sides. The center was present in the majority of instances in girls at the age of 4 and in boys at the age of 6. It was absent in a girl aged 4 and in a boy aged 8.

Pryor found it present in the majority of girls at the age of 4 and of boys at the age of 7, the latter being later than in the Australian series. He found it absent in a girl aged 6 years and 7 months and in a boy aged 8 years and 3 months. He also found it duplicated in a girl aged 7 years and 6 months, while Borovansky and Hnévkovský found double centers in a boy aged 5 years and 10 months.

MULTANGULUM MAJUS

Table XXII represents in the same manner as that for the multangulum minus, the incidence of appearance of this bone.

The youngest girl showing this center was aged 3 years and 5 months, the youngest boy, 5 years and 5 months. In one girl aged 3 years and 5 months, it was not present, while in a boy aged 8 it was also found absent. It was found in both instances in girls aged 4 and in the majority of boys at the age of 5.

Pryor found the center present in a boy aged 4 years and 1 month as well as in the majority of boys at the age of 7 and noted its absence in a girl aged 6 years and 7 months, and in a boy aged 8 years and 10 months.

PRIMARY CENTERS FOR METACARPAL BONES

Primary centers for each of the five metacarpal bones were noted in all fetuses of the length of 62 mm. (11½ weeks) or over in the present series (see Fig. 22).

EPIPHYSIS FOR THE FIRST METACARPAL BONE

The epiphysis for this bone, unlike those for the other metacarpels appears at the base instead of at the distal extremity (see Fig. 3). Additional centers are also frequently found for the distal extremity, in fact Borovansky and Hnévkovský estimate that 50 per cent of the boys of Prague present this epiphysis, while according to them, indications of such tendency may be noted in 70 per cent by the presence of a groove or fissure. Sometimes in the same subject additional epiphyses are also found at the bases of the other metacarpals, thus a boy aged 8 years and 6 months showed indications of these at the distal end of the first metacarpal as well as at the proximal ends of the second and fifth.

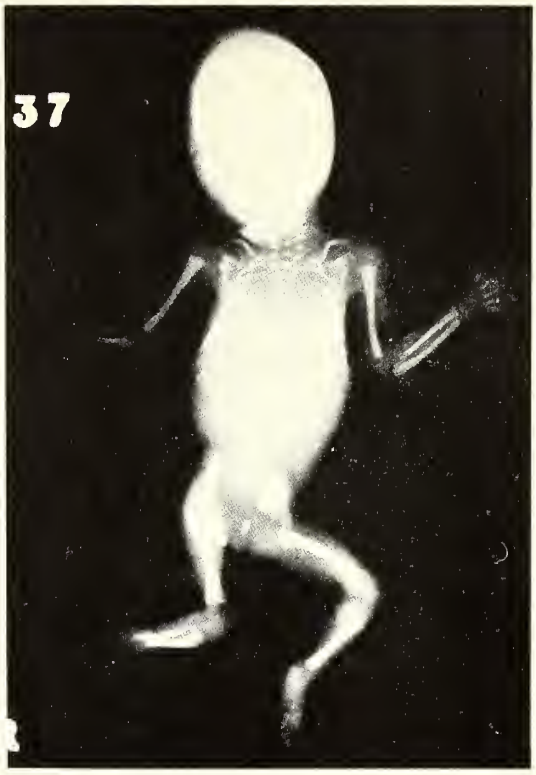

Fig. 22. Female, 165 mm. (20 weeks). Centers for vertebral bodies not united with neural arches. No centers for odontoid process of epistropheus or pubis. Middle row of phalanges present in hand but not in foot. No epiphyses, carpals or tarsals present.

Table XXIII shows the incidence of this

Table XXII

Age	Females				Males			
	Author		Pryor		Author		Pryor	
	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)
3	6	1	9	0	11	0	3	0
4	2	2	14	6	6	0	14	5
5	4	4	30	20	11	7	39	11
6	8	8	33	26	10	7	41	15
7	7	7	14	14	27	24	10	8
8	12	12	4	4	14	13	8	6

Table XXIII

Age	Females				Males			
	Australian		Hindu		Australian		Egyptian	
	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)
0	3	0			4	0		
1	8	7			5	0		
2	13	10			9	5		
3	6	6			9	7		
13	12	11			35	35		
14	4	2	24	13	48	46	110	110
15	7	3	16	6	49	43	42	28
16	14	0	12	1	40	29	101	32
17	10	0	16	3	48	27	96	10
18	21	0	9	1	41	7	71	5
19	6	0	2	0	43	2	24	0

epiphysis, columns (a) showing the number of hands examined and (b) the number of instances in which the epiphyses were present in Australian girls of my series and Hindu girls of Galstaun's series and in Australian boys of my series and Egyptian boys of the series of Sidhom and Derry respectively.

The centers were seen earliest in 2 girls aged 1 year and 2 months and in a boy aged 2 years and 3 months. It was present in the majority of girls during their second year and of boys aged 2. Its absence was noted in a girl aged 2 years and 5 months and in boys aged 3.

The youngest female in whom the epiphysis had fused was aged 13, the youngest male 14. Pryor noted fusion in a boy aged 14 years and 3 months in all five metacarpals. Union was complete in the majority of females at the age of 15 and in the majority of males at 18. Fusion had not yet taken place in girls aged 15 nor in one man aged 19 years and 7 months. In Galstaun's series, union was delayed in some Hindu girls up to the age of 18 years.

Epiphyses for Second, Third, Fourth and Fifth Metacarpal Bones

The epiphyses for these usually appear, unlike those of the phalanges and first metacarpal, at the distal extremities of the second, and very rarely of the fifth. Even when such a center is not quite detached, an indication of such tendency is shown by the appearance of a constriction or fissure, instead of the usual epiphyseal interval. Epiphyses at the base of the second metacarpal were noted in a girl aged 3 and in a boy aged 7 years and 11 months. Very large epiphyses were present on each side in a boy (not included in this series) aged 9 years and 8 months, who is the subject of craniocleidodysostosis.

Table xxiv represents the incidence of the epiphyses of the second, third, fourth and fifth metacarpal bones, columns (a) representing the number of hands examined and columns (b) the number of epiphyses noted in my Australian series, Galstaun's series of Hindu girls and my series of Australian boys respectively.

The youngest subject with epiphyses for the fourth metacarpal was a girl aged 1 year and 10 months and for the fifth metacarpal 1 year and 5 months. In a female aged 1 year and 2 months, centers for the first, second and third metacarpals were present, but those for the fourth and fifth were absent. In a boy in his second year, centers were present for all metacarpals except the first. The epiphyses were present for both girls and for the majority of boys during the second year for second and third

metacarpals and in the majority of both sexes for the fourth metacarpal at the age of 2 in girls and 3 in boys. In a girl aged 2 years and 5 months and in a boy aged 2 no centers were present in any of the metacarpals, while in another boy of 3, there were none for the third, fourth and fifth.

The earliest to fuse in each of these metacarpals was in a girl aged 14 years and 9 months and in a male aged 16 years. Union takes place in the majority of girls at 16 and boys at 18 years of age. In a girl aged 17, none of the centers for these bones had fused, and in another girl aged 18, the center for the second metacarpal was still ununited. In 2 males aged 19 years, none of the centers for these metacarpal bones were united, while in another male of the same age, the center for the third metacarpal was still present although those for the second, fourth and fifth had fused with their respective diaphyses. Non-fusion with the second and third metacarpals was likewise present in a male aged 20 years and 7 months.

Pryor has found all the epiphyses for the metacarpal bones fused in the skeleton of a girl aged 14 years and 3 months.

According to the figures of Galstaun, fusion appears to be complete in the majority of instances in Hindu girls at the age of 14, that is two years earlier than is the case with the girls of the Australian series.

STYLOID PROCESS OF THIRD METACARPAL

Like Pryor, I have not met with any example of a separate epiphysis for the styloid process of the third metacarpal bone as mentioned by Cunningham and by Morris.

PRIMARY CENTERS FOR PROXIMAL PHALANGES

All fetuses of 62 mm. in length ($11\frac{1}{2}$ weeks) and longer showed the centers for the proximal and distal rows of phalanges already present, although those for the middle row were only found in longer fetuses (compare Figs. 7 and 22).

EPIPHYSES FOR THE PHALANGES OF THE FINGERS

Paterson's statement that the phalangeal epiphyses appear "for all practical purposes in all three rows simultaneously" is certainly not borne out by careful study, for there is a considerable variation as the following account shows. Nor are those, even in the same row, simultaneous in their appearance as a rule. Paterson likewise reports that there are no cases of epiphyses in

Table XXIV

Age	Females																Males							
	Author								Galstaun								Author							
	II		III		IV		V		II		III		IV		V		II		III		IV		V	
	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)
1	2	2	2	2	4	1	5	2									3	2	1	1	3	1	3	1
2	11	10	10	9	11	8	10	7									7	4	7	5	8	5	8	3
3	4	4	4	4	5	5	5	5									6	6	7	7	7	7	8	7
14	4	2	2	1	5	4	5	4	24	10	24	10	24	9	24	9	26	26	26	26	31	31	34	34
15	9	5	10	7	11	6	10	6	16	7	16	7	16	7	16	7	27	27	29	29	28	28	29	29
16	11	2	10	1	10	1	9	1	12	1	12	1	12	1	12	1	24	22	25	23	23	22	22	20
17	7	1	6	1	9	1	11	1	16	4	16	4	16	4	16	4	30	19	31	21	31	24	33	25
18	20	1	19	0	17	0	21	0	9	1	9	1	9	1	9	1	33	7	32	7	25	8	32	7
19	3	0	3	0	4	0	4	0	3	0	3	0	3	0	3	0	31	3	33	3	28	2	32	2
20	9	0	10	0	11	0	13	0									20	1	20	1	21	0	21	0

Table XXV

Age	Females		Males	
	(a)	(b)	(a)	(b)
1	2	1	4	0
2	11	7	7	0
13	8	6	17	17
14	3	2	32	29
15	8	3	32	27
16	9	0	24	13
17	14	0	30	14
18	19	0	30	4
19	2	0	33	4

males before the third year, but in this series, those for the proximal phalanges of the index, middle, ring and little fingers, as well as that for the distal phalanx of the thumb are noted in both sexes during the second year.

EPIPHYSIS FOR PROXIMAL PHALANX OF THE THUMB

Table XXV gives the incidence of the appearance of the epiphysis at the base of the proximal phalanx of the thumb, columns (a) representing the number of thumbs examined and columns (b) the number of epiphyses noted.

The earliest epiphyseal centers to appear were in a girl aged 1 year and 11 months and in a boy aged 3 years and 10 months. It was found in all 7 instances at 3 years of age. It was absent in a girl aged 2 years and 5 months, although the epiphyses for all the other proximal phalanges were present, nor was it present in a boy aged 2 years and 6 months. Its presence was noted in the majority of instances in girls at the age of 2.

The earliest centers to fuse were in a girl aged 13 years and 8 months and in a boy aged 14. Fusion was complete in the majority of the instances in girls at the age of 15 and of boys at 17 years of age. The latest unfused were in a girl aged 15 years and 6 months and in a man aged 19 years and 11 months, in whom all the other epiphyseal centers of the row were found fused.

EPIPHYSES FOR PROXIMAL PHALANGES OF THE INDEX, MIDDLE, RING AND LITTLE FINGERS

Table XXVI represents the incidence of the epiphyses at the bases of the proximal phalanges for the index, middle, ring and little fingers, columns (a) showing the number of fingers examined and columns (b) the number of epiphyses noted at each age in each sex respectively.

These centers all appear considerably earlier than in the case of that of the

Table XXVI

Age	Females								Males							
	II		III		IV		V		II		III		IV		V	
	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)
0	0	0	1	1	2	2	2	0	0	0	2	0	2	0	1	0
1	4	4	3	3	3	3	4	3	3	2	2	2	2	2	3	2
2	9	9	8	9	9	9	6	6	6	5	6	5	7	6	7	5
3	4	4	4	4	4	4	4	4	3	3	4	4	5	4	5	4
13	6	5	8	7	7	7	7	6	8	8	6	6	7	7	9	9
14	5	4	3	1	4	2	4	2	21	19	19	18	21	20	23	22
15	10	7	11	5	10	4	7	3	24	20	23	20	25	22	25	23
16	7	1	11	1	11	2	9	1	23	19	23	19	20	17	21	18
17	6	0	4	0	2	0	9	0	30	16	31	18	31	16	26	17
18	19	0	16	0	17	0	17	0	29	5	33	5	32	4	27	4
19	3	0	3	0	3	0	2	0	30	3	30	2	32	2	32	2

Table XXVII

Age	Females								Males							
	II		III		IV		V		II		III		IV		V	
	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)
1	3	1	2	1	2	1	3	1	3	0	2	0	2	0	2	0
2	4	3	4	3	4	3	2	1	4	1	4	1	5	1	3	0
3	1	1	1	1	1	1	2	1	0	0	2	2	1	1	0	0
13	4	3	4	4	5	5	4	4	7	7	6	6	5	5	5	5
14	4	2	4	3	4	3	3	2	19	17	17	16	17	16	17	16
15	7	5	7	6	6	5	6	4	14	10	14	11	14	11	16	31
16	3	0	8	1	7	1	4	0	19	13	21	15	15	11	12	9
17	2	0	3	0	2	0	3	0	17	6	18	7	20	9	18	9
18	14	0	13	0	12	0	13	0	21	2	24	2	22	4	23	3
19	1	0	1	0	0	0	2	0	25	3	29	2	26	2	26	2

thumb. The youngest female to show centers for these was aged 10 months, in whom they were present in the middle finger of the left hand and ring fingers of both hands, but absent in the little fingers on both sides. The earliest centers for all four digits had appeared in a girl aged 1 year and 2 months and in a boy in his second year. In another boy aged 2, although those for the middle and ring fingers were present, the center for the index and little fingers had not yet appeared.

Davies and Parsons found centers present in all digits in a child (sex not stated) aged 9 months.

In the majority of children of both sexes, centers had appeared in all four phalanges during their second year. In every instance centers were found in girls over the age of 10 months except in a girl of 1 year and 6 months, in whom all were present except that for the index, while in another boy aged 3, the centers for the ring and little fingers had not yet appeared. The youngest subjects with fused epiphyses were a girl aged 13 years and 9 months in the case of the index and middle fingers and a girl aged 13 in the case of the little finger. In a girl aged 14 years and 9 months, they were fused in all four digits. In the majority of girls, fusion was completed for the middle finger at the age of 14, and in half of the girls at the same age for the ring and little fingers, while for the index finger union was complete in the majority at the age of 16. For boys fusion took place in the majority at the age of 18 for all four digits. In a girl aged 16, fusion had not yet occurred in any of the four proximal phalanges. In a man aged 19, likewise none was fused while in one man aged 19 years and 7 months, the center for the phalanx for the index finger was still present.

Pryor found all the centers for the phalanges fused in a girl aged 14 years and 3 months.

PRIMARY CENTERS FOR MIDDLE ROW OF PHALANGES

Table XXVII represents the incidence of the epiphyses at the bases of the middle row of phalanges, the arrangement being the same as that for the preceding table for the corresponding row of proximal phalanges.

The earliest centers to appear were in a female aged 1 year and 2 months, in whom it was present in the little finger and 1 year and 11 months in whom it was present in the index, middle and ring fingers but not in the little finger, also in a boy aged 2 years and 3 months in whom it was noted in all four digits. The oldest girls without epiphyses for the index, middle and ring fingers were aged 2 years and 5 months and for the

little finger 3 years and 5 months, while the oldest boys were aged 2 years for the index and middle fingers and 2 years and 6 months for the ring and little fingers. That

Table XXVIII

Age	Females				Males	
	Author		Author		Sidhom and Derry	
	(a)	(b)	(a)	(b)	(a)	(b)
0	1	1	4	0		
1	4	2	3	1		
2	8	8	6	4		
13	4	2	6	6		
14	3	1	17	14	102	86
15	7	2	17	17	40	15
16	6	0	10	8	95	15
17	4	0	26	8	90	9
18	15	0	19	1	70	3
19	3	0	31	3		

for the little finger had not yet appeared in a girl aged 3 years and 5 months. In general, the centers were present in the majority of girls at the age of 2 for the index, middle and ring fingers and in all boys at the age of 4, but insufficient material is available for this particular study.

In the case of the index finger, the youngest girl with fused epiphysis was aged 13 years and 8 months. In a boy aged 14, the centers for the index, ring and little fingers had fused, although that for the middle had not yet united. The youngest boy with fused center for the middle finger was aged 15 years and 11 months. In a girl aged 14 years and 9 months, all four epiphyses were fused, while the oldest girls with unfused centers for the middle and ring fingers were aged 16 and for the index 15 years and 1 month, and in a girl aged 15 years and 11 months those for the middle, ring and little fingers had not yet fused. The oldest males with unfused centers were aged 19 in whom they were present in the whole row. The majority of centers unite at the age of 16 in females and 17 in males.

Pryor found all the centers for the phalanges fused in a girl aged 14 years and 3 months.

PRIMARY CENTERS FOR DISTAL PHALANGES

Like those of the proximal row and the long bones in general, the primary centers for the distal row of phalanges were seen in all fetuses of a length of 62 mm. (11½ weeks) or over, that is earlier than those for the middle row (see Fig. 7).

EPIPHYSIS FOR DISTAL PHALANX OF THUMB

Table XXVIII represents the incidence of the epiphysis at distal phalanx of thumb, columns (a) showing the number of thumbs examined and columns (b) the number of epiphyses noted in my Australian series as well as of the series of Egyptian boys of Sidhom and Derry.

The youngest subject with a center for this epiphysis was a female infant aged 10 months, in whom the centers were also present for the bases of the proximal phalanges of the middle and ring fingers. It was also seen in a male infant 1 year old, in whom none of the epiphyses for the middle row were present, although in all of the proximal row except that for the thumb and all of the metacarpals except the first. The center had not yet appeared in a female child 1 year and 10 months old nor in a male aged 2.

The earliest centers to fuse were at the age of 13 years and 8 months in a girl and 14 in a boy. Half had fused at the age of 13 in females and the majority at 17 in males. The oldest female with unfused epiphysis was aged 15 and the oldest male 19 years and seven months.

Sidhom and Derry found fusion to take place in the majority of Egyptian boys at the age of 15, that is two years earlier than in the Australian series.

EPIPHYSES FOR DISTAL PHALANGES OF INDEX, MIDDLE, RING AND LITTLE FINGERS

Table XXIX represents the incidence of the epiphyses at the bases of the distal pha-

langes of the index, middle, ring and little fingers, the arrangement being the same as those for the preceding tables for the corresponding rows of proximal and middle phalanges.

In a girl aged 1 year and 11 months, the centers were present in the middle and ring fingers but absent in the index and little fingers. In a boy aged 2, the epiphyseal center was present in the index finger on one side only, but absent on the other side as well as in all other distal phalanges on both sides. In a girl aged 3 years and 5 months, centers were present for the whole row. One child aged 3 showed no epiphyses in any of these fingers. In a boy aged 2 years and 6 months, the center for the ring finger had not yet appeared.

In a boy aged 14 years and 9 months, the centers for the index, middle and ring fingers had fused. In a boy aged 14, the centers for all these phalanges had united. In a girl aged 15 years and 6 months, the centers were fused in the case of all the digits. In the female the majority of the epiphyses fuse at the age of 15, in the male at 16 for the middle finger and 17 for the index, ring and little fingers. Thus, it appears that the center for the middle finger fuses at an earlier date than the others in the male at least. Unfused epiphyses were present for all fingers at the age of 15 in a female and for the ring finger in a girl aged 16, while the oldest male with non-fusion for all the distal phalanges (both sides) was aged 17.

Pryor found all the centers for the phalanges fused in a girl aged 14 years and 3 months.

Table XXIX

Age	Females								Males							
	II		III		IV		V		II		III		IV		V	
	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)
1	3	0	4	2	2	1	2	0	0	0	0	0	0	0	0	0
2	0	0	0	0	1	1	0	0	2	1	2	0	3	0	3	0
14	3	1	4	2	4	2	3	3	15	14	12	11	13	12	13	12
15	7	3	7	2	8	2	6	2	8	5	8	6	9	8	10	8
16	6	0	7	0	7	1	4	0	8	5	12	5	9	8	9	7
17	4	0	2	0	3	0	4	0	15	6	15	6	17	6	17	7

SESAMOID OSSICLES

Sesamoid ossicles, usually two, are practically constantly found over the heads of the first metacarpal bones in the palmar aspect. Similar ossicles, usually single, are generally, but not invariably, found over the heads of the second metacarpal on the radial side and the fifth metacarpal bone on the ulnar aspect, but similar ossicles over the third and fourth are rather rare. Usually, also, very much smaller ossicles are present in the tendon of the flexor longus pollicis beneath the head of the proximal phalanx of the thumb, and these are always single.

PROXIMAL SESAMOID BONES OF THUMB

Table XXX represents the incidence of the presence of the proximal sesamoid of the

Table XXX

Age	Females		Males	
	(a)	(b)	(a)	(b)
9	2	1	5	0
10	3	2	1	0
11	4	3	5	0
12	6	2	9	1
13	3	3	4	2
14	3	3	15	14
15	8	8	24	23

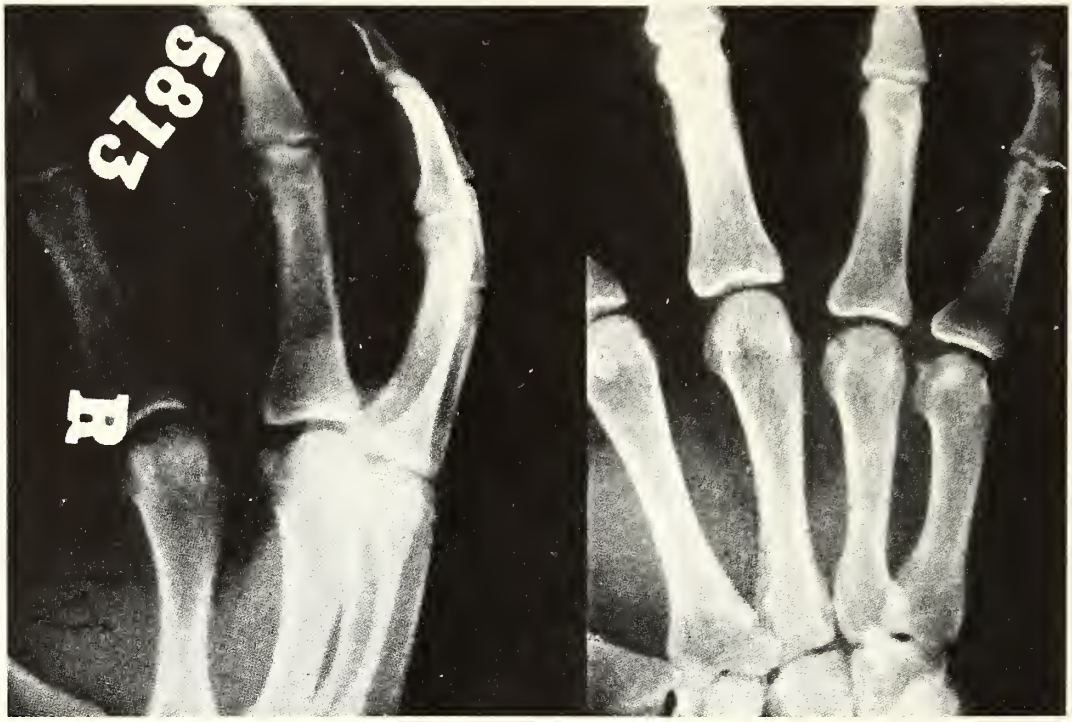

Fig. 23. Male, aged twenty-one. Sesamoids present over heads of all metacarpals.

thumb, columns (a) representing the number of thumbs examined and columns (b) the number of instances in which these ossicles have been observed at each age in each sex.

The earliest centers were noted in a girl aged 9 years and 5 months on one side at least and a boy aged 12 years and 8 months on both sides, the majority of girls aged 13 and half the boys of the same age showing sesamoids. It was absent in girls aged 12 and also absent in a boy aged 15. It was likewise noted absent in a subject aged 17 of unknown sex.

SESAMOID OF INDEX FINGER

As before, Table XXXI represents the incidence of the sesamoid for the index finger, columns (a) representing the number of these digits examined and columns (b) the number in which such sesamoids have been observed.

The earliest examples were noted in a girl aged 11 years and 6 months and in boys aged 14. It is present in half of the instances in girls at 15 and in the majority of males at 19. However, it is commonly absent at a much later date; thus, it was not present on

Table XXXI

Age	Females		Males	
	(a)	(b)	(a)	(b)
11	4	1	1	0
12	5	1	5	0
13	3	0	1	0
14	2	0	10	3
15	6	3	10	2
16	4	4	10	6
17	3	3	11	3
18	5	1	17	5
19	3	1	18	11
20	6	5	12	5
21	2	2	16	12
22	3	2	11	5
23	6	3	10	9
24	1	1	9	6
25	0	0	4	2
26	0	0	1	0
27	0	0	2	0
28	0	0	1	1

either side in a female of 23 although present over the fifth metacarpals, nor was it present in a male aged 27. Older subjects were not studied, but it is likely that in certain individuals it may never occur.

SESAMOIDS OF MIDDLE AND RING FINGERS

These are rare. In the middle finger, instances were noted in a girl aged 13 years and 10 months and in a boy aged 14 years and 0 months. In a man aged 21 (see Fig. 23) sesamoid bones were present at the heads of all the metacarpals, those for the middle and ring fingers being on the radial aspects, while two were present for the fifth metacarpal. In another subject of the same age of unknown sex, a very large sesamoid appeared to be situated over the middle of the head of the third metacarpal bone.

SESAMOID OF THE LITTLE FINGER

As before, Table XXXII represents the incidence of the sesamoid for the little finger, columns (a) representing the number of these digits examined and columns (b) the number in which such sesamoids have been observed.

The earliest examples were seen at the age of 13 years and 10 months in the female and 14 years in a male. At the age of 15 in the female and 17 in the male the majority showed presence of these ossicles. However, instances were found at the age of 23 in the female and 27 in the male in whom they were not present.

Table XXXII

Age	Females		Males	
	(a)	(b)	(a)	(b)
13	6	1	1	0
14	1	1	11	1
15	6	4	14	5
16	4	4	11	5
17	4	4	15	8
18	4	3	24	14
19	3	2	16	11
20	9	9	10	6
21	3	3	14	13
22	6	5	14	10
23	7	5	13	13
24	3	3	8	6
25	0	0	7	5
26	0	0	4	2
27	0	0	1	0

Table XXXIII

Age	Females		Males	
	(a)	(b)	(a)	(b)
14	1	1	3	0
15	0	0	8	2
16	3	3	4	2
17	2	2	7	5
18	5	5	8	5
19	1	0	10	8
20	3	2	4	4
21	0	0	8	7
22	1	1	3	2
23	0	0	7	5
24	0	0	5	2
25	0	0	2	1

DISTAL SESAMOID OF THE THUMB

Again, as before, Table XXXIII represents the incidence of the sesamoid over the head of the proximal phalanx of the thumb, columns (a) representing the number of thumbs examined and columns (b) the number in which such sesamoids have been observed.

This is a very small ossicle found at the head of the proximal phalanx of the thumb near the insertion of the tendon of the flexor longus pollicis into the base of the distal phalanx.

The earliest sesamoids were seen at the age of 14 years and 9 months in a girl and 15 in boys. The majority of females aged 16 and half of the males aged 16 showed its presence. Examples of absence were noted at the age of 20 in the female and 25 years and 2 months in the male.

EARLIEST PRIMARY CENTERS FOR LOWER LIMB

The primary centers for the ilium, femur, tibia and fibula were all present in a fetus of 32.5 mm. (49 days after single coitus), as well as in all larger fetuses (Fig. 7). Although the centers for the distal phalanges

Table XXXIV

Age	Females		Males	
	(a)	(b)	(a)	(b)
10	5	2	12	0
11	17	2	18	0
12	7	1	17	0
13	6	4	11	5
14	8	8	14	4
15	13	13	22	14
16	18	17	12	9
17	10	10	29	25

of the hallux were not present in a female fetus of 62 mm. ($11\frac{1}{2}$ weeks) these were found in all fetuses of 70 mm. (12 weeks) or over. The centers for the metatarsals and proximal row of phalanges were, however, present in the 62 mm. fetus, as well as in all larger fetuses.

PRIMARY CENTERS FOR THE OS COXAE

The ilium was present in all fetuses of 32.5 mm. (49 days) and older (see Fig. 7) and the ischium in those of 109 mm. (15 weeks) and longer, while the os pubis, which appeared considerably later was first noted in a male fetus of 165 mm. (20 weeks) and in a female of 205 mm. (23 weeks), although absent in a male of 180 mm. (21 weeks) (see Fig. 11).

CENTERS OF OSSIFICATION IN Y-SHAPED CARTILAGE

One or more centers of ossification are usually present in the Y-shaped cartilage in the floor of the acetabulum, but the precise roentgenographic demonstration of these presents considerable difficulties.

UNION OF CENTERS FOR ILIUM, ISCHIUM AND PUBIS

Table XXXIV represents the incidence of fusion of the three primary centers for the ilium, ischium and pubis, columns (a) indicating the number of hips examined and columns (b) the number of instances in which these centers have fused with each other.

The youngest girl in whom the cartilaginous junction (Y-shaped cartilage) of the three component parts of the os coxae had completely ossified was aged 10 years and 6 months and the youngest boy 13 years and 7 months (in each case on both sides). Fusion had taken place in the majority of the girls at the age of 13 and of boys not until 15 years of age. The oldest subjects with unfused centers were a girl aged 16 years and 10 months and a boy aged 17 years and 11 months.

EPIPHYSIS FOR ACETABULAR MARGIN

Morrison describes and illustrates separate centers of ossification on the supero-anterior, superior and supero-posterior aspects, respectively, of the rim of the acetabuli, which, when ossified, serve to deepen the cavity. The superior is first noted in a boy at the age of 12, in whom it was present on the left but not on the right. In the same boy, it was present on both sides at the age of 12 years and 3 months and at 13 years and 2 months showed two centers on the left and only one on the right. At 13 years and 6 months, the right center had fused and at 14 years and 4 months, the left center likewise disappeared. The right hip is the site of tuberculous disease, probably accounting in part for the change. In another boy, the subject of multiple osteomyelitis, at 13 years and 6 months, a center is shown for the left postero-superior acetabular rim, but not until 14 years and 8 months, when the left epiphysis is "nearly closed" is a similar center noted on the right side, which is still present at the age of 16 years. In a third boy aged 14, well defined epiphyses were noted on the posteroanterior margin of both acetabula.

Morrison states that frequently separate permanent ossicles are found on the anterior, superior and posterior aspects, respectively, of the acetabular rim. However, it is exceptional for epiphyses in other regions to persist throughout life as permanent and independent ossicles.

In the present series, a detached ossicle was noted on the acetabular margin on each

side below the anterior inferior spine in a boy aged 15 years and 3 months.

Under the name os acetabuli, Freedman illustrates similar centers on the superolateral aspect of the acetabular margin, in each case bilateral in two subjects aged 14 and 26 respectively.

UNION OF ASCENDING ISCHIAL WITH DESCENDING PUBIC RAMUS

Table XXXV represents the incidence of fusion of the ascending ramus of the ischium with the descending ramus of the pubis, columns (a) indicating the number of pelves examined, and (b) the number of instances in which these rami had fused at each age group in each sex respectively.

The youngest girl showing fusion of the rami was aged 3 years and 11 months, the youngest boy 4 years and 0 months, on both sides in each case. The majority showed union at the age of 8 in girls and 7 in boys. Davies and Parsons noted fusion in a boy aged 3. In a boy aged 11 years and 4 months, union was not complete on either side, but in a girl of 11, fusion was present on one side, but not on the other.

EPIPHYSIS FOR ILIAC CREST

Table XXXVI shows the incidence of the presence of one or more epiphyseal centers along the iliac crest, columns (a) indicating the number of pelves examined and (b) the number of instances in which the epiphyses were noted.

TABLE XXXV

Age	Females		Males	
	(a)	(b)	(a)	(b)
3	17	2	22	0
4	14	2	26	2
5	10	4	31	11
6	1	0	11	2
7	10	4	24	13
8	9	8	12	7
9	13	13	9	6
10	4	1	12	10
11	12	11	16	12

TABLE XXXVI

Age	Females		Males	
	(a)	(b)	(a)	(b)
12	11	2	7	0
13	11	2	10	4
14	10	9	11	0
15	19	19	11	4
16	24	24	11	6
17	20	14	29	18
18	46	44	24	18
19	18	11	35	28
20	32	25	16	10
21	23	9	26	6
22	25	5	16	3

The youngest subjects in whom these epiphyses were present were a girl aged 12 years and 0 months and a boy aged 13 years and 4 months in whom it was present on each side in each case. Cleaves reports epiphyses well developed in a boy of only 12 years. In females the majority of epiphyses appear at the age of 14 and in males at 16 years of age, but the maximum incidence is at 15 and 16 in girls and 19 in young men. Epiphyses were present in the female at the age of 22 years and 3 months and in the male at the age of 22 years and 9 months. The majority were fused at the age of twenty-one in both sexes.

SYMPHYSIS PUBIS

An epiphysis for the symphysis pubis, such as is usually described, has not been found in this series, nor can a description of such as actually observed in the roentgenogram be discovered in the literarure, so that either it does not exist at all or it is exceedingly rare. The symphysis pubis is very favorably situated for examination, so that if such were actually present, it could scarcely escape recognition. Similarly no trace of any epiphysis about the pubic crest or pubic spine has yet been met with.

Burman, Weinkle and Langsam, in a roentgenological study of the development of the symphysis pubis, make no reference to the presence of any epiphysis in this region.

EPIPHYSIS FOR THE ANTERIOR SUPERIOR ILIAC SPINE

This appears to be a rare epiphysis and in this series was met with only three times, on each occasion in females aged 13 years and 5 months, 14 and 17 years respectively,

Fig. 24. Female, aged seventeen. Epiphysis for anterior superior iliac spine. (Courtesy of the *Journal of Anatomy*.)

in one of them at least, it was present on both sides (see Fig. 24). Possibly this epiphysis might be considered a separate fragment of the epiphysis for the iliac crest.

ANTERIOR INFERIOR ILIAC SPINE

Morrison illustrates what he describes as a "normal epiphysis of the anterior inferior iliac spine," but the age and sex are not given, and the subject appears to be an adult. I have never seen a roentgenographic demonstration of an undoubted epiphysis for the anterior inferior iliac spine. However, such would be in a difficult situation for such a study.

Fig. 25. Female, aged twenty. Note epiphyses along perineal margins anterior to ischial tuberosities. Centers for iliac crests not yet fused.

EPIPHYSIS OVER THE TUBER ISCHII

The epiphysis for this process forms a thin scale along the ascending ramus of the ischium (see Fig. 25) and descending ramus of the pubis even as far as the apex of the perineal arch. This is the epiphysis described by Stevenson as the ramal epiphysis which he regards as distinct from that of the tuber ischii.

Table XXXVII represents the incidence of the presence of this epiphysis, columns (a) indicating the number of pelves examined, and (b) the number of centers observed at each age group in each sex respectively.

Table XXXVII

Age	Females		Males	
	(a)	(b)	(a)	(b)
13	4	2	9	2
14	7	2	14	0
15	2	0	18	3
16	9	8	12	0
17	5	2	25	9
18	21	16	15	6
19	7	6	23	14
20	32	26	10	2
21	12	6	19	3
22	24	2	9	0
23	15	0	11	0
24	21	2	17	0

The youngest girl in whom this epiphysis was found was aged 13 years and 5 months, and the youngest boy 13, in each case being present on both sides. Table XXXVII appears to indicate that the epiphysis is present in the majority of females at the age of 16 and of males at the age of 19. The maximum incidence is between the ages of 16 and 20 in females and 19 in males. Fusion is present in the majority of males at the age of 20 and of females at the age of 21. It seems to be more than twice as frequently demonstrable relatively between the ages of 13 and 24 inclusive in females (72 times in 159 instances, or 45.3 per cent) than in males (39 times in 182 instances, or 21.1 per cent). It was noted on both sides in a female aged 24 and in a male aged 21.

PRIMARY CENTER FOR HEAD OF FEMUR

This was noted in all fetuses of 32.5 mm. (49 days) or longer (see Fig. 7).

EPIPHYSIS FOR HEAD OF FEMUR

The incidence of the presence of this center is represented by Table XXXVIII, columns (a) indicating the number of hips examined and (b) the number of instances in which these epiphyses are noted to be present.

TABLE XXXVIII

Age	Females		Males	
	(a)	(b)	(a)	(b)
0	14	12	19	9
13	6	4	13	13
14	10	2	14	13
15	7	0	18	15
16	14	2	12	7
17	7	0	24	10
18	21	1	19	2
19	11	0	27	0
20	29	0	10	2

Of 237 instances in females and 263 in males within 48 hours after birth, Menees and Holly found this center present twice only in females (0.8 per cent) and once in a male (0.3 per cent).

The epiphysis for the head of the femur apparently always appears during the first year after birth except in those rare instances in which it appears just before birth. It was present in a male infant and in a girl aged 9 months, in each case on both sides, but in each of 2 boys aged 9 months, it was present on the right side, although absent on the left. It was not present on either side in a girl aged 2 months nor in a boy aged 3 months. In all of 25 instances in girls and 17 in boys in their second year this center was found to be present.

The youngest subjects in whom this epiphysis had fused were a girl aged 13 years and 4 months and a boy aged 14, in the former instance on both sides. At the age of 14, the great majority had fused in girls, but not until the age of 17 in males had the majority united. This is much earlier than the dates given by Paterson, namely 17 for females and 18 for males. The oldest subjects with unfused epiphyses were 18 years and 2 months in a female and 20 years and 2 months in a male (both sides).

TABLE XXXIX

Age	Females		Males	
	(a)	(b)	(a)	(b)
2	18	4	16	0
3	16	10	20	0
4	14	8	22	7
5	11	11	28	21
6	6	6	6	4
14	8	0	13	13
15	2	0	14	10
16	6	1	6	4
17	5	0	19	8

EPIPHYSIS FOR GREATER TROCHANTER

Table XXXIX represents the incidence of the presence of the epiphysis for the greater trochanter, columns (a) indicating the number of hips examined and (b) the number of instances in which these epiphyses were observed at each age group in each sex respectively.

The youngest girl with a center for the greater trochanter was aged 2 years and 7 months in whom it was present on both sides, while the youngest boys were aged 4 years and 4 months. The majority of epiphyses appeared at the age of 3 in girls and 5 years in boys. Borovansky and Hnévkovský found this center present in a boy aged 3 years and 5 months. The oldest girls in whom the epiphyses had not yet appeared on either side were aged 4, while in a boy of 6 the epiphyses were likewise absent on both sides.

The earliest to fuse were in a girl aged 14 years and 4 months and in a boy of 15 years and 10 months. The majority were fused in girls at the age of 14 and in boys at 18. Union had not yet taken place on either side in a girl aged 16 years and 10 months nor in a boy aged 17 years and 6 months.

Table XL

Age	Females		Males	
	(a)	(b)	(a)	(b)
8	8	0	11	1
9	11	6	12	1
10	0	0	13	3
11	12	4	14	2
12	7	0	11	6
13	4	0	6	0
14	6	0	15	13
15	4	0	15	12
16	7	1	10	4
17	5	0	20	6

Morrison illustrates a second epiphysis situated at the highest part of the epiphysis for the greater trochanter in two subjects aged 9 and 10 years respectively, but does not mention in which sex. He likewise shows illustrations of a number of instances of separate ossicles in this same position.

EPIPHYSIS FOR LESSER TROCHANTER

Table XL illustrates the incidence of occurrence of the epiphysis for the lesser trochanter, columns (a) indicating the number of hips examined and (b) the number of epiphyses observed at each age group in each sex respectively.

The youngest girl with epiphysis for this process was aged 9 years in whom it was present on the right but not on the left and the youngest boy 8 years and 11 months. At the age of 14 it was present in boys in the great majority of cases. The maximum incidence was in girls at the age of 9 and in boys at the age of 14. Although the center was present in 48 of 127 (37.8 per cent) instances in boys aged 9 to 17, it was only noted 11 times in 64 instances (17.2 per cent) in girls of the same ages. It seems probable that this center is not constantly present and perhaps is much more common in boys than in girls. The center was found present in a girl aged 16 years and 10 months and in a boy aged 17 years and 11 months.

DISTAL FEMORAL EPIPHYSIS

Probably the distal femoral epiphysis is the first epiphysis to appear in the human subject and was noted earliest in a female of 262 mm. and in a male of 263 mm. (both 30 weeks) in length. It was still absent, however, in a female of 280 and in a male of 283 mm. (each 32 weeks). It was found present in all 11 fetuses of 294 mm. (33 weeks) and longer, as well as in all 14 instances in babies examined during the first year after birth.

Hill recorded this center in a male fetus estimated at 24 weeks, although absent in 40 other males and 33 females of the same estimated age. He also found it in a female aged 28 weeks (estimated).

Pryor noted the presence of epiphyses in each of two females within 2 days after premature birth at 8 months, but it was not present in a male under similar circumstances. Of 48 girls and 43 boys examined during the first 9 days after birth, this epiphysis was present in every instance except in 2 boys.

Hill found this center in all of 35 females and 47 of 50 male full time fetuses.

Of 237 instances in females and 263 in males within 48 hours after birth, Menees and Holly found this center present in all except 1 female (99.6 per cent) and 4 males (98.4 per cent).

Adair and Scammon found this center in all of 45 females and 55 males within 48 hours after birth except in a female and a male, both of whom were frankly premature.

In obstetric practice the roentgenographic demonstration of the presence of this epiphysis gives some clue to the period of gestation.

Table XLI gives the incidence of this

Table XLI

Age	Females		Males	
	(a)	(b)	(a)	(b)
14	5	4	8	8
15	5	2	9	9
16	11	8	12	10
17	6	0	17	11
18	10	1	13	8
19	4	1	12	1

epiphysis, columns (a) indicating the number of knees examined, and (b) the number of instances in which these have been observed at each age group in each sex respectively.

The youngest girl in whom this epiphysis had fused was aged 14, the youngest boys 16. The center was fused in the majority of females at the age of 17 and in the majority of males at 19. Instances of non-fusion were met with in both sexes at the age of 19.

CENTER FOR PATELLA

The patella is best demonstrated in young children in the lateral view of the knee joint (Fig. 26), for its absence cannot always be definitely determined in the posteroanterior view as the early nucleus may be obscured behind the shadow of the lower extremity of the femur.

Sometimes an additional center on the upper and outer aspect is present. This forms the patella bipartita or patellula. Borovansky and Hnévkovský found one in a boy aged 14. In this series an example was seen in a female aged 27 years and 6 months. Borovansky and Hnévkovský also show an illustration of a separate ossicle at the apex of the patella in a boy aged 16 years and 11 months.

Table XLII represents the incidence of occurrence of the center for the patella, columns (a) indicating the number of knees examined in my series of Australian girls and boys and the series of Swedish girls and boys of Hellmer respectively, and (b) the number of instances in which these centers were found in the same series.

Fig. 26. Male, aged six years eight months. Tongue-shaped process for anterior tubercle of tibia not yet appeared.

The youngest girl showing a center for the patella was aged 2 years and 6 months, the youngest boy 3 years and 11 months. It was present in half of the girls from the age of 2 and the majority of boys at the age of 5. In a girl aged 3 years and a boy aged 8, the bone had not yet appeared. Borovansky and Hnévkovský found a center present in a boy aged 3 years and 7 months.

Table XLII

Age	Females				Males			
	Author		Hellmer		Author		Hellmer	
	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)
2	10	5	12	0	8	0	14	0
3	2	1	17	6	8	2	17	0
4	1	1	13	11	6	2	13	3
5	6	6	14	14	5	4	14	10
6	1	1	17	17	4	4	17	17
7	2	2	19	19	9	9	19	19
8	1	1	22	22	7	6	22	22

Fig. 27. Female, aged twenty-nine. Note fabella.

Hellmer found in a girl aged 1 year and 11 months a center present on the left, but absent on the right. Six months later in the same subject, they were present on both sides. In the larger Swedish series of Hellmer, the center was present in the majority of girls aged 4 and of boys aged 5.

FABELLA (SEE FIG. 27)

Table XLIII represents the incidence of the presence of the fabella, columns (a) indicating the number of knees examined, and columns (b) the number of instances in which this sesamoid has been observed.

Of this series, the youngest female showing this sesamoid bone was aged 17, the youngest male being 16 years and 5 months of age. It is by no means common, for of 176 individuals aged 16 to 29, it was present only 15 times, or 8.5 per cent.

I have learned of an instance where this ossicle was surgically removed under the impression that it was a pathological foreign body.

PRIMARY CENTER FOR TIBIA

As for the femur and fibula, all fetuses of 32.5 mm. (49 days) and longer showed the primary center for the tibia already present (see Fig. 7).

PROXIMAL EPIPHYSIS OF THE TIBIA

The proximal tibial epiphysis is second in order of appearance only to that of the distal femoral epiphysis, being first noted in a female of 294 mm. (33 weeks) and in a male also of 294 mm., but was absent in a female of 324 mm. (37 weeks) and in a male 334 mm. (38 weeks) in length. It was present in every one of 14 instances in babies during the first year after birth.

Hill noted this center in a fetus of estimated age of 32 weeks.

Pryor noted this center present 2 days after premature birth at 8 months in a female, but it was absent in a male and in a female after premature birth at 8 months. Of 47 female and 42 male infants in the first 9 days after birth, this center was noted absent in 7 females and 13 males, being relatively twice as frequently absent in boys as in girls. Its absence was also noted in a girl aged 23 days.

Adair and Scammon report its presence in 37 of 45 females and 42 of 54 males within 48 hours after birth.

Of 35 female and 49 male full time fetuses, Hill recorded the presence of this epiphysis in 25 and 32 respectively.

Menees and Holly noted its presence in 191 females and 212 males (80.6 per cent of each sex) in 237 instances in girls and 263 in boys within 48 hours after birth.

Table XLIII

Age	Females		Males	
	(a)	(b)	(a)	(b)
16	5	0	9	2
17	6	1	13	1
18	6	1	7	0
19	4	0	9	1
20	6	1	4	1
21	7	1	19	3
22	6	0	13	0
23	8	0	10	1
24	4	0	9	0
25	0	0	5	0
26	0	0	4	0
28	2	0	2	0
29	0	0	1	0

Table XLIV represents the incidence of occurrence of this epiphysis, columns (a) indicating the number of knees examined and (b) the number of centers observed at each age group in each sex respectively.

The tongue-shaped prolongation which forms the anterior tubercle is not usually present until after the age of 8 (see Figs. 26 and 28). Usually it is an extension of the proximal epiphysis forward over the upper end of the diaphysis. Sometimes an additional center is present over this process. One such was found in a girl aged 10 years and 6 months, in whom no trace of a tongue-shaped process had yet appeared.

Table XLIV

Age	Females		Males	
	(a)	(b)	(a)	(b)
14	6	5	8	8
15	5	2	9	9
16	7	3	10	8
17	7	1	17	11
18	12	1	12	4
19	4	1	16	2

The earliest to fuse were in a girl aged 14 and in a boy aged 16 (both sides). Although the center had disappeared in the majority of girls at the age of 15, it was not until the age of 18 that the majority of epiphyses in boys had united. Instances of non-fusion were found in both sexes at the age of 19.

Fig. 28. Age eighteen. Large hiatus behind tongue-shaped process of anterior tubercle is present on both sides and is probably not of traumatic origin.

PRIMARY CENTER FOR FIBULA

As in the case of the femur and the tibia, a primary center for the fibula was seen in every fetus of 32.5 mm. (49 days) or longer.

PROXIMAL EPIPHYSIS OF FIBULA

Table XLV represents the incidence of occurrence of the proximal epiphysis of the fibula, columns (a) indicating the number of knees examined and (b) the number of such epiphyses noted at each age group and in each sex respectively.

The earliest centers were in a girl aged 2 years and 11 months and in a boy aged 3 years and 4 months, in each case on both sides. It was present in the majority of girls at the age of 3 and of boys at 5. Its absence was noted in a girl aged 4 and in a boy aged 5.

The earliest epiphyses to fuse were in a

Table XLV

Age	Females		Males	
	(a)	(b)	(a)	(b)
2	20	2	11	0
3	5	3	11	5
4	6	5	15	6
5	8	8	8	7
14	5	4	9	9
15	4	1	10	10
16	8	6	10	8
17	7	1	16	11
18	10	1	15	10
19	5	0	16	3

Table XLVI

Age	Females		Males	
	(a)	(b)	(a)	(b)
13	18	17	9	9
14	5	2	25	23
15	6	0	15	11
16	12	5	10	8
17	10	0	24	7
18	11	0	16	1

girl aged 14 and in a boy aged 16, the majority being at the age of 17 in females and 19 in males. The oldest subjects in whom fusion had not yet appeared were a female aged 18 and a male aged 19 years and 8 months.

DISTAL EPIPHYSIS OF THE TIBIA

This was found to be present in every infant examined including a girl aged 7 months (both sides) and a boy aged 9 months. Borovansky and Hnévkovský found its presence in a boy aged 3 months and 3 weeks.

Table XLVI represents the incidence of occurrence of this epiphysis, columns (a) indicating the number of ankles examined and columns (b) the number of such epiphyses observed at each age group and in each sex respectively.

The youngest girl to show fusion of this epiphysis was aged 13 and the youngest boy 14 years and 9 months. Table XLVI shows that the majority of epiphyses fuse at the age of 14 in girls and 17 in boys. Instances of non-fusion were noted in a female aged 16 years and 4 months and in a male aged 18.

As is the case with the distal epiphysis of the radius and ulna, so are the distal tibial and fibular centers fused approximately simultaneously with the shaft. However, in the girl of 13, quoted above, although the center for the distal end of the tibia had fused, that for the fibula had not yet done so, being thus a violation of the oft-quoted rule that the first epiphyses to appear are the last to unite.

OS MALLEOLI

In a male aged 17 years and 7 months, an ossicle was seen on both sides at the tips of the medial malleoli, and is clearly demonstrable in both the anteroposterior and lateral views. I can nowhere find a record of such an ossicle in the literature. The term os malleoli is suggested.

DISTAL EPIPHYSIS OF FIBULA

This was found present on both sides in a female infant aged 11 months and was likewise found in a boy aged 1 year and 9 months, but was not present in a girl of 9 months nor in a boy aged 1 year and 8 months, although present in all of 7 instances in girls and 3 of 4 boys during their second year.

Table XLVII represents the incidence of occurrence of this epiphysis, columns (a) indicating the number of ankles examined, and (b) the number of epiphyses observed in each age group in each sex respectively.

Table XLVII

Age	Females		Males	
	(a)	(b)	(a)	(b)
14	5	2	24	24
15	6	0	15	11
16	12	5	12	10
17	9	0	21	6
18	9	0	14	1

The earliest epiphyses to fuse were found in a girl aged 14 years and 10 months and in a boy aged 15 years and 8 months (both sides). The majority had united in girls at the age of 14 and in boys at 17. Instances of non-fusion were noted in a girl aged 16 years and 4 months and in a boy aged 18.

TARSUS

The calcaneus, talus and in the female only, the cuboid, usually appear before birth. The navicular and the three cuneiforms have not been noted at this period.

Pryor found centers for both calcaneus and talus present in all three premature 8 months babies of both sexes, as well as in

all of 90 other infants of both sexes during the first 9 days after birth.

In my series, no infant was found in whom the centers for the calcaneus, talus or cuboid had not already appeared. The calcaneus usually has an additional epiphysis for the posterior aspect of the heel, known as the apophysis. The other tarsal bones usually ossify from a single center, but sometimes the talus has a separate center for the medial tubercle, which, when it fails to unite with the primary center, forms the os trigonum. In this series, both the navicular and the first cuneiform have been noted arising from two centers.

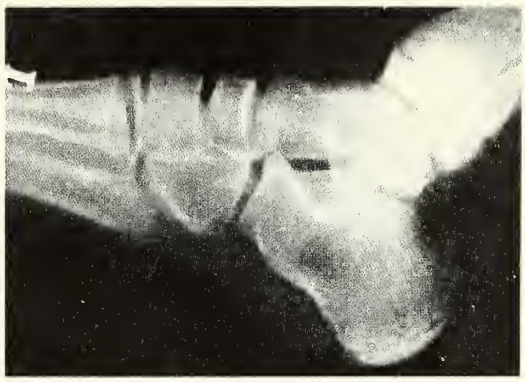

Fig. 29. Male, aged thirteen. Note epiphysis at base of fifth metatarsal and apophysis for calcaneus.

CENTER FOR CALCANEUS

The calcaneus was first noted in a male fetus of 165 mm. (20 weeks) and in a female of 205 mm. (23 weeks). It was, however, absent in a much larger female fetus of 280 mm. (31½ weeks), although present in 11 of 13 fetuses from 171 to 280 mm. in length (20 to 31½ weeks) as well as in all 12 larger specimens.

Hill reported this center present in 8 of 31 fetuses estimated 16 weeks' gestation.

APOPHYSIS OF CALCANEUS (SEE FIG. 29)

Table XLVIII represents the incidence of occurrence of the apophysis of the calcaneus, columns (a) indicating the number of heels examined and columns (b) the number of instances in which such apophysis has been observed at each age group in each sex respectively.

Table XLVIII

Age	Females		Males	
	(a)	(b)	(a)	(b)
7	6	4	8	3
8	4	4	8	5
12	1	0	7	7
13	13	9	8	8
14	4	1	20	18
15	7	0	8	4
16	10	2	16	9
17	7	0	22	2
18	8	0	10	1

The earliest centers to appear were in a girl aged 7 years and 1 month and in a boy aged 7 years and 5 months. Borovansky and Hnévkovský noted the center in a boy aged 6 years and 2 months. The apophysis was absent in a girl aged 7 years and 9 months and in a boy aged 8 years and 7 months, but present in all of 22 instances in children aged 9 to 11 inclusive. It was present in the majority of girls at the age of 7 and of boys aged 8.

The earliest to fuse with the primary center were in a girl aged 12 years and 10 months and in a boy aged 14 years and 6 months. The apophyses were fused in the majority of girls aged 14 and of boys aged 17. The oldest subjects with ununited apophysis were a female aged 16 and a male aged 18.

CENTER FOR TALUS

The center for the talus was seen earliest in a male fetus of 180 mm. (21 weeks) long and in a female of 205 mm. (23 weeks). Its absence was noted in a male of 224 mm. (25 weeks) and in a female of 280 mm. (31½ weeks), the latter being the only instance of 18 fetuses of 233 mm. (26 weeks) or longer.

Hill recorded a center present in a fetus of an estimated age of 16 weeks.

The center for the talus has been found present in all subjects examined after birth.

Table XLIX

Age	Females		Males	
	(a)	(b)	(a)	(b)
1	5	5	2	0
2	11	7	11	5
3	9	8	10	9
4	8	6	9	9
5	3	3	10	9

CENTER FOR CUBOID

The center for the cuboid was found in 2 fetuses only, namely a male of 295 mm. (33½ weeks) and a female of 315 mm. (36 weeks), but was absent in 6 others of a length of 294 mm. (33 weeks) or more.

Hill recorded this center in a fetus of estimated age of 24 weeks.

A center for this bone was present in every foot in the series examined alive after birth.

Pryor found this bone present in a female 2 days after premature birth at 8 months, but it was absent in another female and in a male, both also prematurely born at 8 months. He also examined 89 infants, 47 females and 42 males, during the first 9 days after birth and found the center present in 31 females and 11 males, that is approximately 66 per cent in girls and 25 per cent in boys. It was, however, found absent in a boy aged 13 days and in a girl aged 25 days.

Menees and Holly found it, however, in 133 females (56.5 per cent) and 92 males (35.0 per cent) when examining 237 females and 263 males within 48 hours after birth. Adair and Scammon found it present in 20 of 45 females and 18 of 55 males within 48 hours after birth.

Hill noted among 35 female and 50 male full time fetuses, 18 and 23 centers respectively.

CENTER FOR TARSAL NAVICULAR

Table XLIX records the incidence of occurrence of this bone, columns (a) representing the number of feet examined, and columns (b) the number of instances in which centers have been observed at each age group in each sex respectively.

The youngest girl with center for the navicular was aged 1 year, the youngest boy 2 years and 6 months. In a girl aged 4 years and 4 months and in a boy aged 5, the center had not yet appeared. The center was present in all 5 instances in girls during their second year and the majority of boys at the age of 3.

In a girl aged 3 years and 4 months, three centers were noted, while in a boy aged 3, two centers were found for this bone.

CENTER FOR FIRST CUNEIFORM

Table L represents the incidence of occurrence of the center for the first cuneiform, columns (a) indicating the number of feet examined, and columns (b) the number of instances in which such centers were found at each age in each sex respectively.

The earliest epiphyses to appear were in a girl aged 2 years (both sides) and in a boy aged 2 years and 6 months. In the girl, it was present on both sides in the first, second and third but not in the fourth and fifth metatarsals, in the boy absent in the four outer metatarsals. In another girl aged 2 years and 7 months, it was also present in the first but absent in all the others. The center was absent in a girl aged 2 years and 4 months and in a boy aged 3 years and 6 months. It was present in the majority of instances in girls at 2 and in boys at the age of 3. Davies and Parsons report the presence of an epiphysis in a female aged 10 months.

Table L

Age	Females		Males	
	(a)	(b)	(a)	(b)
2	10	9	9	2
3	6	6	5	4
14	1	0	10	10
15	5	0	5	4
16	7	2	15	11
17	7	0	22	7
18	5	1	11	1

The earliest to fuse were in a girl aged 14 and in a boy aged 15. Although the majority of girls aged 14 showed fusion, it was not until the age of 17 years that this was the case in boys. Instances of non-fusion were found at the age of 18 in both sexes.

EPIPHYSES FOR SECOND, THIRD, FOURTH AND FIFTH METATARSALS

Table LI represents the incidence of occurrence of the epiphyseal centers for the second, third, fourth and fifth metatarsal bones, columns (a) indicating the number of feet examined, and columns (b) the number of centers observed at each age group in each sex respectively.

Table LI

Age	Females								Males							
	II		III		IV		V		II		III		IV		V	
	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)
2	10	4	10	4	8	0	8	0	6	0	4	0	3	0	3	0
3	4	4	4	4	4	2	4	2	2	1	2	1	2	0	2	0
4	3	3	3	3	3	3	3	3	3	3	3	3	3	2	3	1
14	1	0	1	0	1	0	1	0	9	9	8	8	8	8	8	8
15	7	0	7	0	7	0	7	0	6	4	6	4	6	4	6	4
16	7	1	7	3	7	1	6	1	13	9	14	10	13	9	11	7
17	6	0	5	0	5	0	6	0	18	3	18	3	21	5	21	4
18	5	1	5	1	5	1	5	1	10	0	10	0	9	1	9	1

In a girl aged 2 years, centers were present on both sides for the heads of the second and third metatarsal bones, but had not yet appeared for the fourth and fifth. In a female aged 3 years and 4 months, centers for all five metatarsals were present. In a girl aged 3 years and 5 months, centers were present for the second and third but not for the fourth and fifth. In a boy aged 4, those for the first, second, third and fourth metatarsals were present, but that for the fifth had not yet appeared. In another boy aged 4 years and 6 months, on the right side, centers were present for all five metatarsals, but on the left, although present for the first, second and third, were absent for the fourth and fifth. In a girl aged 2 years and 7 months, and in a boy aged 3 years, although centers were present for the first, epiphyses were absent for all the other metatarsal bones. It is present in at least half of the children of both sexes at the age of 3 for the second and third, and half the girls for the fourth and fifth, and in boys at 4 for the fourth and 5 for the fifth metatarsal.

The youngest subjects in whom the epiphyses were found fused in all four outer metatarsals were a girl aged 14 and a boy aged 15 years and 2 months (both sides). In a female aged 18 years, centers were present in all five metatarsal bones. They were likewise present in a female aged 17. In a male aged 18, they were absent in the case of the second and third metatarsal bones, although present for the fourth and fifth. Fusion was complete in the majority of girls at the age of 14 and of boys at 17 years of age.

EPIPHYSIS AT BASE OF FIFTH METATARSAL

Sometimes an epiphysis is seen at the base of the fifth metatarsal (see Fig. 29). When this fails to unite with the shaft, it has been described as the os vesalii, which, according to Woollard, has only been recorded 4 times in roentgenograms. Table LII represents the incidence of its occurrence, columns (a) indicating the number of feet examined and columns (b) the number of such centers noted at each age group in each sex respectively.

Fig. 30. Female, aged two years three months. Two centers present for first cuneiform.

The youngest female with such an epiphysis was aged 12, the youngest male 13 years and 4 months, but instances were noted at the age of 17 in subjects of unknown sex. Its maximum incidence, in males at least, appears to be at the age of 13 when it was present in 3 of 4 instances. Altogether it occurred 15 times in 100 instances in subjects between the ages of 12 and 17 inclusive. It is evidently not constantly present. Borovansky and Hnévkovsky noted a center in a boy aged 11 years and 7 months, but in this series, it was not present in any of 2 instances in girls and 4 in boys aged 11.

Table LII

Age	Females		Males	
	(a)	(b)	(a)	(b)
12	3	1	4	0
13	12	2	4	3
14	1	0	15	6
15	5	0	5	0
16	6	0	9	1
17	10	0	19	0

SESAMOID OSSICLES OF HALLUX

There are usually a pair of these beneath the head of the first metatarsal bone on the plantar aspect. The medial sesamoid is frequently split into two by an irregularly transverse fissure taking on the appearance as though fractured. Occasionally the lateral sesamoid is similarly split. These ossicles were found at the age of 9 years and 7 months in a girl and 12 years and 5 months in a boy. Splitting of one of the ossicles on each side was noted in a boy aged 16 years and 4 months. This sesamoid was not present on either side in a girl aged 11 nor in a boy aged 11 years and 2 months, but is noted in all subjects aged 12 years and older.

Table LIII

Age	Females		Males	
	(a)	(b)	(a)	(b)
2	9	8	6	1
14	1	0	6	6
15	7	0	5	3
16	6	1	16	11
17	7	2	18	3
18	5	1	9	0

SESAMOID OF SECOND METATARSAL BONE

This was seen upon both sides in a female aged 24 years and 8 months.

SESAMOID OF FIFTH METATARSAL BONE

The only instances of these were seen in females (on both sides in each case) aged 21 years and 2 months and 21 years and 10 months respectively.

PRIMARY CENTERS FOR PROXIMAL ROW OF PHALANGES

In this series every fetus of 62 mm. (11½

weeks) or longer showed the presence of the primary centers for the proximal row of phalanges.

EPIPHYSIS FOR PROXIMAL PHALANX OF HALLUX

Table LIII represents the incidence of the occurrence of the epiphysis at the base of the proximal phalanx of the great toe, columns (a) indicating the number of such toes examined and columns (b) the number of epiphyses observed at each age group in each sex respectively.

The epiphysis at the base of the phalanx was found in a girl aged 2 years (both sides) and in a boy at the age of 2 years and 6 months. In a girl aged 2 years and 4 months it was absent although present in the other phalanges in the row, while it was absent in all five proximal phalanges in a boy aged 2 years and 6 months.

Davies and Parsons record the presence of this epiphysis in a female aged 10 months.

The youngest subjects in whom this epiphysis was found fused were a girl aged 14 and a boy aged 15. Fusion had taken place in the majority of girls at the age of 14 and of boys at 17 years of age. Nonfusion was present in a male aged 17 (although fusion was complete in all the other proximal phalanges) and in a female aged 18.

EPIPHYSES FOR PROXIMAL PHALANGES OF SECOND, THIRD, FOURTH AND FIFTH TOES

Table LIV represents the incidence of occurrence of these epiphyses at the bases of the corresponding proximal phalanges, columns (a) representing the number of feet examined, and columns (b) the number of centers noted at each age group in each sex respectively.

Table LIV

Age	Females								Males							
	II		III		IV		V		II		III		IV		V	
	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)
1	2	2	2	1	2	1	2	0	1	0	0	0	0	0	0	0
2	9	8	9	8	9	8	9	7	6	4	6	4	6	4	6	2
14	1	0	1	0	1	0	1	0	6	4	6	4	7	4	8	2
15	7	0	7	0	6	0	6	0	5	3	5	3	5	3	5	3
16	6	0	6	0	6	0	7	1	14	10	15	10	14	10	15	8
17	6	0	5	0	5	0	5	0	19	4	19	3	19	3	19	4
18	5	1	5	1	6	1	6	1	10	0	9	0	9	0	9	1

The epiphyses at the bases of all the proximal phalanges were found in a girl aged 2 years and in a boy aged 2 years and 6 months. In a girl aged 1 year, it was present in the second, third and fourth but not in the fifth toe. In a boy aged 2 years, the centers for the second, third and fourth were present, but not that for the fifth. In a girl aged 2 years and 7 months and in a boy aged 2 years and 6 months, it had not yet appeared in any of the toes.

The youngest subjects in whom these were found fused with the shafts were a girl aged 14 and a boy 15 years of age. As with the metatarsals, the centers were fused in the majority of girls at the age of 14 and of boys at 17 years of age. In a girl of 18, nonfusion was present in all four digits. This was likewise the case in a boy aged 17. In a male aged 18, although fusion was present in the case of the second, third and fourth toes, that for the little toe was still ununited.

Table LV

Age	Females		Males	
	(a)	(b)	(a)	(b)
2	6	4	4	0
3	4	2	2	2
4	1	1	3	2
5	0	0	3	2
6	1	1	1	1
7	1	1	2	0
8	0	0	8	6
9	1	1	4	2
12	2	0	2	2
13	9	6	3	3
14	0	0	6	6
15	6	0	4	1
16	6	0	12	6
17	2	0	15	0
18	2	1	9	0

PRIMARY CENTERS FOR MIDDLE ROW OF PHALANGES

The primary centers for the middle row of phalanges of the toes appear very much later than those of the corresponding phalanges of fingers, which are all present in fetuses of 62 mm. (11½ weeks) or longer. In the foot they appear approximately consecutively in order from the second to the fifth toe. The earliest centers for the second toe were seen in a male of 185 mm. (21 weeks) and in a female of 220 mm. (25 weeks); for the third toe, 171 mm. (20 weeks) in a male and 220 mm. (25 weeks) in a female; fourth toe, 233 mm. (26 weeks) in the female and 275 mm. (31 weeks) in the male; while that for the little toe in the male was noted at 275 mm. (31 weeks). The largest fetuses showing absence of these phalanges in the case of the second toe were 147 mm. (18 weeks) in the male and 165 mm. (20 weeks) in the female; third toe, 150 mm. (18 weeks) in the female and 234 mm. (27 weeks) in the male; fourth toe, 220 mm. (25 weeks) in the female and 234 mm. (27 weeks) in the male; and lastly, for the little toe, a female of 220 mm. (25 weeks) and a male of 234 mm. (27 weeks).

In a boy aged 4 years and 0 months, the primary center for the middle phalanx of the little toe had not yet appeared upon either side.

As the various epiphyses at the bases of the middle row of phalanges develop at different periods, these will be described in separate groups.

EPIPHYSIS AT BASE OF MIDDLE PHALANX OF SECOND TOE

Table LV represents the incidence of occurrence of the epiphyseal center at the base of the middle phalanx of the second toe, columns (a) indicating the number of feet examined and (b) the number of centers observed at each age group and in each sex respectively.

The earliest center was found in a girl aged 2 years and 0 months, in whom it was also present in the third and fourth but not in the fifth. In another girl aged 2 years and 4 months, it was present in all the phalanges of the row. In a boy aged 3 years and 5 months, it was present in the third as well as in the second and in another boy of 3, although present in these two digits, it was absent in the fourth and fifth. It was not present in a girl aged 3 although present in the other phalanges of the row, nor in a boy aged 9 years and 8 months in any of these phalanges on either side. It was present in the majority of girls at the age of 2 and of boys at the age of 3.

The earliest fusion was noted in a girl aged 12 years and 10 months and in a boy aged 15. In a female aged 18 and in a male aged 16 years and 6 months it had not yet fused.

EPIPHYSES AT BASES OF MIDDLE PHALANGES OF THIRD AND FOURTH TOES

Table LVI represents the incidence of occurrence of these epiphyses, columns (a) indicating the number of feet examined and (b) the number of centers observed at each age group in each sex respectively.

These being relatively vestigial digits, the development of their epiphyses is irregular and quite different from the others.

They were both present on both sides in a girl aged 2 years and 0 months. In another girl aged 1 year and 0 months, it was present for the middle toe but not for any other phalanx of the row. In a boy aged 2 years and 0 months, they were present on the right side for the third, fourth and fifth, but not for the second and on the left for the fifth, but not for the second, third and fourth, while in another boy of the same age, it was not present for the third toe on either side, although that for the fourth was present on the right side but not on the left. In a boy aged 5 years and 2 months, they were both present on both sides. They appeared to be present in the majority of females from the age of 2 and of males at the age of 5, but are earlier in the case of the third than in that of the fourth.

In this series, it is impossible to determine the existence of fusion or not, for the non-observance of these epiphyses may be due to one of the three following circumstances: (*a*) stage before appearance of epiphysis, (*b*) non-development of epiphysis and (*c*) fusion of epiphysis with diaphysis. The oldest subjects in whom an epiphysis for the third toe was present was a female aged 18 and a male aged 16 years and 6 months, in whom it was present in the third but not in the fourth toe, and for the fourth toe a girl aged 13 years and 6 months and a boy aged 16. Of 27 and 23 instances respectively in girls aged 5 to 16 inclusive, only 4 epiphyses were present for the third and but 2 for the fourth toe although there were 24 and 14 epiphyses respectively in 48 and 46 instances in boys of the same ages. However, between the ages of 1 to 4 (inclusive) 10 epiphyses were present in 12 instances for the third, and 8 of 13 instances for the fourth, while the corresponding figures for boys were 2 of 8 for the third, and 1 of 9 for the fourth toe.

Table LVI

Age	Females				Males			
	III		IV		III		IV	
	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)
1	2	2	2	0	0	0	0	0
2	5	4	6	4	4	1	4	1
3	4	3	4	3	1	1	1	0
4	1	1	1	1	3	0	4	0
5	0	0	0	0	3	2	4	3
6	1	0	1	0	2	2	1	0
7	1	0	1	0	2	0	2	0
8	0	0	0	0	8	6	8	4
9	1	1	0	0	2	1	4	2
10	0	0	0	0	2	1	3	1
11	0	0	1	0	2	2	2	1
12	3	0	2	0	2	2	1	1
13	9	3	8	2	3	1	3	0
14	0	0	0	0	6	3	4	1
15	6	0	4	0	4	1	4	0
16	6	0	6	0	12	3	10	1
17	2	0	3	0	16	0	15	0
18	3	1	4	0	7	0	8	0

EPIPHYSIS AT BASE OF MIDDLE PHALANX OF LITTLE TOE

Of 165 instances, including 55 females and 103 males aged 1 to 18, this epiphysis was found 9 times (5.4 per cent) only. It is

the exception rather than the rule for this epiphysis to be present at any age. The youngest girl with such an epiphysis was aged 2 years and 4 months and the youngest boy 2 years and 0 months (both sides) and the oldest girl was aged 13 years and 6 months (both sides) and the oldest boy 12 years and 1 month.

PRIMARY CENTER FOR DISTAL PHALANX OF HALLUX

Although not present in the female fetus of 62 mm. (11½ weeks), all fetuses measuring 70 mm. (12 weeks) or over showed the center for the proximal phalanx of the hallux.

EPIPHYSIS AT BASE OF DISTAL PHALANX OF HALLUX

Table LVII represents the incidence of occurrence of the epiphysis at the base of the distal phalanx of the hallux, columns (a) indicating the number of big toes examined and columns (b) the number of centers observed at each age group in each sex respectively.

Table LVII

Age	Females		Males	
	(a)	(b)	(a)	(b)
13	9	6	3	3
14	0	0	7	7
15	7	0	5	5
16	6	0	12	8
17	4	0	16	0
18	4	1	10	1

An instance of absence of this epiphysis was noted on both sides in a subject (not included in this series) of cleidocraniodysostosis aged 9 years and 8 months.

This epiphysis was present in a girl aged 1 year and 0 months and in a boy aged 1 year and 9 months.

Fusion was present in a girl aged 13 years and 0 months and in a boy aged 15. In the majority of girls aged 15 and of boys aged 17, fusion was complete. Union had not yet occurred on either side in a boy aged 16 years and 6 months, nor was it fused in a girl aged 18.

PRIMARY CENTERS FOR DISTAL PHALANGES OF SECOND, THIRD, FOURTH AND FIFTH TOES

The earliest that the primary centers for the distal phalanges of the second, third, fourth and fifth toes appeared in each case was in a male fetus of 109 mm. (15 weeks). In the case of the little toe, it was present on one side, and in a female fetus of 150 mm. (18 weeks) for the second, third and fourth toes, although absent for the fifth, but was present in all distal digits in a female of 233 mm. (26 weeks) long. In the male fetus of 70 mm. (12 weeks) the whole row was absent, while the distal phalanges for the fourth and fifth toes were not present in a male fetus of 165 mm. (20 weeks), while in a female of 220 mm. (25 weeks) there were not yet any centers for the little toe.

EPIPHYSES AT BASES OF DISTAL PHALANGES OF SECOND, THIRD AND FOURTH TOES

The youngest subject in whom these have appeared in the case of the second and third toes was aged 3 (unknown sex). In a girl aged 3 years and 11 months, those for the third and fourth toes were present. In a boy aged 4 years and 0 months, centers were present on both sides for the fourth although absent on the right side for the third. They were likewise noted in a boy aged 5, while in a girl aged 6 years and 6 months, it was present for the second toe. It was absent in all three digits in a girl aged 3 and a boy aged 8.

Table LVIII shows the incidence of occurrence of these epiphyses, columns (a) indicating the number of feet examined, and columns (b) the number of centers observed at each age group in each sex respectively.

The earliest to fuse were in a girl aged 12 years and 10 months, and in boys aged 15. The majority were fused in girls in the case

Table LVIII

Age	Females						Males					
	II		III		IV		II		III		IV	
	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)
12	2	1	2	1	2	1	1	1	1	1	1	1
13	7	1	7	1	8	5	2	2	2	2	3	3
14	0	0	0	0	0	0	5	5	5	5	4	4
15	4	0	4	0	5	0	3	0	4	1	3	0
16	5	0	6	0	5	0	9	2	9	2	10	2
17	1	0	1	0	3	0	10	0	9	0	10	0
18	4	1	4	1	5	1	7	0	5	0	6	0

of the second and third digits at the age of 13 and in boys aged 15 in all three. Instances of non-fusion were found in a female at 18 and in males at the age of 16.

EPIPHYSIS AT BASE OF DISTAL PHALANX OF LITTLE TOE

Table LIX represents the incidence of occurrence of the epiphysis at the base of the distal phalanx of the fifth toe, columns (a) indicating the number of toes examined and (b) the number of such epiphyses at each age group and in each sex respectively.

The earliest centers to appear in each sex were aged 3. The oldest girl with an epiphysis was aged 13 years and 8 months and the oldest boy 16.

In Table LX the centers given prior to birth represent the earliest periods at which they were observed, while after birth, they indicate the ages at which at least half of the centers and epiphyses have appeared or fused in each sex respectively.

Although the cuboid has been shown as having been found in a male fetus prior to birth, it is also listed among those appearing in males during their first year, when the majority of such centers first make their appearance.

AGES AT WHICH OSSIFICATION CENTERS AND EPIPHYSES APPEAR AND FUSE

Table LXI takes into account only instances noted by the author and the various authorities specified. Columns (a) represent in years and months or years only the age of earliest appearances noted; (b) in years only the age at which at least half of these are noted; (c) age in years and months or years only of oldest subjects in whom these have not yet appeared; (d) age in years and months or years only of earliest age at which fusion has been noted; (e) age in years only at which at least half have fused, and (f) age in years and months or years only of oldest subjects in whom fusion had not yet taken place. Figures in parentheses indicate length of fetuses in millimeters.

OBSTETRIC APPLICATIONS

As the various centers of ossification are rarely clearly recognizable in living intra-

Table LIX

Age	Females		Males	
	(a)	(b)	(a)	(b)
3	2	1	1	1
4	0	0	3	0
5	0	0	3	1
6	0	0	2	1
7	1	1	2	2
8	0	0	6	5
9	0	0	4	2
10	0	0	3	2
11	2	0	3	1
12	1	0	1	0
13	6	1	3	0
14	0	0	4	1
15	4	0	5	0
16	6	0	9	1

TABLE LX

CHRONOLOGICAL ORDER OF APPEARANCE AND FUSION OF OSSIFICATION CENTERS

Before Birth. (Actual observations only.)

30 mm. (9 weeks). Clavicle.

32.5 mm. (49 days after single coitus). Proximal 10 pairs of ribs, primary centers of scapula, humerus, radius, ulna, ilium, femur, tibia and fibula.

62 mm. (11½ weeks). Arches cervical spines, bodies and arches thoracic and lumbar spines, bodies first and second sacral, eleventh pair of ribs, primary centers metacarpals, proximal and distal rows of phalanges of fingers, metatarsals, proximal row of phalanges of toes.

Estimated age 12 weeks. Semicircular canals (Hill).

109 mm. (15 weeks). Bodies lower five cervical and third sacral spines, arch first sacral, middle row of phalanges of fingers, ischium, distal phalanges of second, third, fourth and fifth toes.

134 mm. (17 weeks). Male. Cervical rib.

147 mm. (18 weeks). Arch second sacral.

Male. Body fourth sacral.

150 mm. (18½ weeks). Female. Arch third and fourth sacral. Body fourth sacral.

165 mm. (20 weeks). Bodies atlas, epistropheus.

Female. Body fifth sacral, cervical rib.

Male. Arch third and fourth sacral, pubis, calcaneus, talus.

Estimated age 20 weeks. Hyoid (Hill).

171 mm. (20½ weeks). Male. Arch fifth sacral, middle phalanx third toe.

180 mm. (21 weeks). First, second and third sternebrae. Male. First sacral lateral mass.

185 mm. (21½ weeks). Male. Middle phalanx of second toe.

205 mm. (23 weeks). Female. Arch fifth sacral, pubis, calcaneus, talus.

218 mm. (25 weeks). Fourth sternebra.

220 mm. (25 weeks). Female. First, second and third sacral lateral mass, middle phalanges of second and third toes.

233 mm. (26½ weeks). Female. Middle phalanx of fourth toe.

262 mm. (30 weeks). Distal epiphysis of femur. Female. First segment of coccyx.

275 mm. (31 weeks). Male. Middle phalanx of fourth and fifth toes.

283 mm. (32 weeks). Fifth sternebra.

295 mm. (33 weeks). Sixth sternebra, proximal epiphysis of humerus and tibia. Male. First segment of coccyx and cuboid.

312 mm. (35 weeks). Male. Third sacral lateral mass.

315 mm. (36 weeks). Female. Cuboid.

After Birth.

First year. Capitate, hamate, epiphyses for head of femur, distal tibia and fibula, center for third cuneiform.

Female. Epiphysis greater tubercle humerus, capitulum, distal radius, proximal phalanges of middle, ring and little fingers, distal phalanx of thumb.

Male. Cuboid.

Second year. Epiphyses second and third metacarpals, proximal phalanx of index.

Female. Epiphyses first metacarpal, proximal phalanx of thumb, middle phalanges of middle and ring fingers, distal phalanges of middle and ring fingers, centers tarsal navicular, first and second cuneiforms, epiphyses proximal phalanges of second, third and fourth toes, middle phalanx third toe.

Male. Capitulum, epiphyses distal radius, proximal phalanges of middle, ring and little fingers.

Age 2. Epiphysis fourth metacarpal.

Female. Epiphyses fifth metacarpal, middle phalanges of index and little fingers, centers patella, epiphysis first metatarsal, proximal phalanges of hallux and fifth toes, middle phalanges of second and fourth toes.

Male. Epiphyses greater tubercle of humerus, first metacarpal, distal phalanges of thumb and index, center for first cuneiform, epiphyses for proximal phalanges of second, third and fourth toes.

Age 3. Epiphyses for second and third metatarsals.

Female. Epiphyses distal phalanges index and little fingers, greater trochanter, proximal fibula, distal phalanges of third and fourth toes.

Male. Centers lunate, triquetrum, epiphyses fifth metacarpal, proximal phalanx thumb, middle phalanges middle and ring fingers, centers tarsal navicular and second cuneiform, epiphyses first metatarsal, proximal phalanges hallux and fifth toe, middle phalanx of second toe.

Age 4. Epiphysis fourth metatarsal.

Female. Proximal epiphysis radius, centers carpal navicular, lunate, triquetrum, multangula minus et majus, epiphysis head of fifth tarsal.

Union of greater tubercle with head of humerus.

Male. Epiphyses middle phalanges index and little fingers, distal phalanges middle and ring fingers.

Age 5. Female. Epiphyses medial epicondyle, distal ulna.

Male. Proximal epiphysis radius, centers carpal navicular, multangulum majus, epiphysis distal phalanx little finger, greater trochanter, center patella, epiphyses proximal fibula, head of fifth metatarsal, middle phalanges third and fourth toes, distal phalanges of second, third and fourth toes.

Union of head with greater tubercle of humerus.

Age 6. Female. Epiphysis distal phalanx second toe.

Union epiphyses middle phalanges third and fourth toes.

Male. Distal epiphysis ulna, center multangulum minus.

Age 7. Female. Apophysis of calcaneus.

Male. Medial epicondyle.

Union rami ischium and pubis.

Age 8. Female. Epiphysis olecranon.

Union rami of ischium and pubis.

Male. Apophysis of calcaneus.

Age 9. Female. Epiphysis of trochlea.

Age 10. Female. Center pisiform.

Male. Epiphyses trochlea, olecranon.

Age 11. Female. Epiphysis lateral epicondyle.

Male. Center pisiform.

Age 12. Male. Epiphysis lateral epicondyle, center sesamoid hallux.

Age 13. Centers proximal sesamoids thumb.

Female. Epiphysis angle of coracoid, center sesamoid hallux.

Fusions, angle of coracoid, conjoint distal epiphyses to shaft humerus, distal phalanx thumb, ilium and ischium to pubis, distal phalanges second and third toes.

Male. Fusions middle phalanges third and fourth toes.

Age 14. Female. Epiphyses acromion, iliac crest, lesser trochanter.

Union epiphyses medial epicondyle, olecranon, proximal radius, proximal phalanges middle, ring and little fingers, distal phalanges index, middle and ring fingers, proximal femur, greater trochanter, distal tibia and fibula, apophysis calcaneus, epiphyses all metatarsals, proximal phalanges all toes.

Male. Union distal epiphyses of humerus to each other.

Age 15. Union epiphysis distal phalanx fourth toe.

Female. Centers for sesamoids of index and little fingers.

Union of epiphyses first metacarpal, proximal phalanges thumb and index, distal phalanx little finger, proximal tibia, middle phalanx second, distal phalanx hallux.

Male. Epiphysis for acromion.

Union of ilium and ischium with pubis, distal phalanges second and third toes.

Age 16. Centers for distal sesamoids of thumb.

Female. Epiphysis tuber ischii.

Fusions four inner metacarpals, middle row of phalanges of fingers.

Male. Epiphysis iliac crest.

Fusions distal conjoint epiphysis to shaft of humerus, medial epicondyle, olecranon, proximal radius, distal phalanx middle finger, greater trochanter.

Age 17. Union of epiphysis acfomion.

Female. Clavicle.

Union proximal conjoint epiphysis to shaft of humerus, distal ulna, distal femur, proximal fibula.

Male. Fusion epiphyses proximal phalanges thumb, middle row phalanges of fingers, distal phalanges thumb, index, ring and little fingers, proximal femur, distal tibia and fibula, apophysis of calcaneus, epiphyses all metatarsals, proximal row phalanges of toes, middle phalanx second toe, distal phalanx hallux.

Age 18. Female. Union epiphyses clavicle, distal radius.

Male. Center for sesamoid of little finger.

Fusion epiphyses proximal humerus to shaft, all metacarpals, proximal phalanges index, middle, ring and little fingers, proximal tibia.

Age 19. Male. Center for sesamoid of index, epiphysis tuber ischii.

Fusions distal radius, and ulna, femur, proximal fibula.

Age 20. Male. Fusion tuber ischii.

Age 21. Fusion iliac crest.

Female. Fusion tuber ischii.

Male. Epiphysis clavicle.

Table LXI

	(a)		(b)		(c)		(d)		(e)		(f)	
	Female	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female	Male
Epiphysis clavicle	11 7	11 8	17	21					18		26 11	25
Epiphysis inferior angle scapula	17	16 10			18 11							
Epiphysis base of coracoid process	0 8	5 11			7 6	10 3						
Ditto Menees and Holly												
Epiphysis angle of coracoid	10 2	14 7	13						13		16	19
Epiphysis tip of coracoid		14 7				16						
Epiphysis acromion	12 0	14 11	14	15					17	17	16 1	19 2
Epiphysis head of humerus	(294)	(295)	(315)	(295)								
Ditto Menees and Holly			P.N.	P.N.								
Epiphysis greater tubercle of humerus	0 8	0 6	<1	2	0 11	0 9						
Union greater tubercle head of humerus							3 7		4	5	6	6 6
Union conjoint proximal epiphysis humerus							15 9	16	17	18	20 5	19 2
Epiphysis lateral epicondyle	8 6	10 7	11	12	16	16						
Epiphysis capitulum	0 9	0 11	<1	1		0 8						
Epiphysis trochlea	7	8 9	9	10	16	16						
Fusion ep. lat. epicond., capit., troch.							10	12		14	16	15
Fusion distal conjoint ep. to shaft							13 4	14 7	13	16	16	16
Ditto Sidhom and Derry (Egyptian)										15		
Epiphysis medial epicondyle	2 2	5 5	5	7	6	7 3	10	12	14	16	16	17 0
Ditto Sidhom and Derry (Egyptian)										16		19 3
Ditto Galstaun (Hindu)									14		18	
Epiphysis olecranon	6	7	8	10	10		13 10		14	16	16 0	17 6
Ditto Galstaun (Hindu)											18	
Epiphysis proximal radius	3 4	3 4	4	5	6	8	13 10	14	14	16	19 10	20 5
Ditto Davies and Parsons	2											
Epiphysis distal radius	0 9	1 1	<1	1	1 2	1 7	15 11	17 3	18	19	20 5	23
Ditto Sidhom and Derry (Egyptian)								16		19		
Ditto Galstaun (Hindu)							14	19				
Epiphysis distal ulna	5	5 4	5	6	7	8 6	15 0	17 3	17	19	22	23
Ditto Paterson	4											
Ditto Sidhom and Derry (Egyptian)								15 11		18		
Ditto Galstaun (Hindu)							14					
Ditto Pryor (U.S.A.)									16	19		
Epiphysis styloid process ulna		13 10										
Ditto Borovansky and Hnévkovský (Prague)		5 10										
Center carpal navicular	4 10	4 6	4	5	5 5	8						
Ditto Pryor (U.S.A.)	3 6	4 4	4	7	6 4	8 3						
Center lunate	2 7	1	4	3	3 5	6 11						
Ditto Pryor			3	4	6 3							
Center triquetrum	1 5	2 3	4	3	3	7 3						
Ditto Pryor (U.S.A.)		1 9	2									
Center pisiform	7 2	7	10	11	10 8	14 7						
Center hamate	0 9	0 9	<1	<1		0 2						
Ditto Menees and Holly	2 days	2 days										
Center capitate	0 9	0 2	<1	<1		1 wk.						
Ditto Pryor (U.S.A.)		2 days			0 3	0 7						
Ditto Menees and Holly (U.S.A.)	2 days	2 days										
Center multangulum minus	3 5	3 10	4	6	4	8						
Ditto Pryor (U.S.A.)				7	6 7	8 3						
Center multangulum majus	3 5	5 5	4	5	3 5	8						
Ditto Pryor (U.S.A.)		4 1		7	6 7	8 10						
Epiphysis first metacarpal	1 2	2 6	1	2	2 5	3	13	14	15	18	15	19 7
Ditto Sidhom and Derry (Egyptian)										16		
Ditto Galstaun (Hindu)							14		15			
Epiphysis second metacarpal, distal	1 2	1	1	1	2 5	2	14 9	16	16	18	17	20 7
Ditto Galstaun (Hindu)									14		18	
Epiphysis second metacarpal, base	3	7 11				8 6						
Epiphysis third metacarpal	1 2	1	1	1	2 5	3	14 9	16	16	18	17	19
Ditto Davies and Parsons	1 3											
Ditto Galstaun (Hindu)									14		18	
Epiphysis fourth metacarpal	1 10	1	2	3	2 5	3	14 9	16	16	18	17	19
Ditto Galstaun (Hindu)									14		18	
Epiphysis fifth metacarpal	1 5	1	2	3	2 5	3	14 9	16	16	18	17	19
Ditto Galstaun (Hindu)									14		18	
Epiphyses all metacarpals (Pryor)							14 3					
Epiphysis proximal phalanx thumb	1 11	3 10	1	3	2 5	2 6	13 8	14	15	17	15 6	19 11
Epiphysis proximal phalanx index	1 2	1	1	1		2	13 8	14	15	18	16	19 7
Epiphysis proximal phalanx middle fin.	0 10	1	<1	1		2	13 8	14	14	18	16	19
Epiphysis proximal phalanx ring finger	0 10	1	<1	1		3	14 9	14	14	18	16	19
Epiphysis proximal phalanx little finger	1 2	1	<1	1	1 6	3	13	14	14	18	16	19
Epiphysis middle, ring and little finger (Sidhom and Derry)												19 3
Epiphysis middle phalanx index	1 11	4	2	4	2 5	2	13 8	14	16	17	15 1	19
Epiphysis middle phalanx middle finger	1 11	2 3	1	3	2 5	2	14 9	15 11	18	17	16	19
Epiphysis middle phalanx ring finger	1 11	2 3	2	4	3 5	2 6	14 9	14	16	17	16	19
Epiphysis middle phalanx little finger	1 2	2 3	2	4	3 5	2 6	14 9	14	16	17	15 11	19
Epiphysis distal phalanx thumb	0 10	1	<1	2	1 10	2	13 8	14	13	17	15	19 7
Ditto Sidhom and Derry (Egyptian)										15		
Epiphysis distal phalanx index	3 5	2	3	2	1 11	2	14 9	14	14	17	15	17
Epiphysis distal phalanx middle finger	1 11	4	1	4	1 2	2	14 9	14	14	16	15	17
Epiphysis distal phalanx ring finger	1 11	4	1	4	2 5	2 6	14 9	14	14	17	16	17
Epiphysis distal phalanx little finger	3 5	5	3	5	1 11	2	15 6	14	15	17	15	17
Epiphyses distal phalanges, all fingers (Pryor)							14 3					
Center proximal sesamoid, thumb	9 6	12 8	13	13	12	15						
Center, sesamoid index	11 6	14	15	19	23	27						
Center, sesamoid middle finger	13 10	14 0										
Center, sesamoid ring finger		21										
Center, sesamoid little finger	13 10	14	15	17	23	27						
Center, distal sesamoid thumb	14 9	15	16	16	20	25 2						
Union, centers ilium, ischium and pubis							10 6	13 7	13	15	16 10	17 11

TABLE LXI—*Continued*

	(a)		(b)		(c)		(d)		(e)		(f)	
	Female	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female	Male
Union rami of ischium and pubis							3 11	4 0	8	7	11	11 4
Ditto Davies and Parsons								3				
Epiphysis iliac crest	12 0	13 4	14	16	14		17 1		21	21	22 3	22 9
Epiphysis anterior superior iliac spine	13 5				17							
Epiphysis tuber ischii	13 5	13	16	19					21	20	24	21
Proximal epiphysis femur	0 9	0 6	<1	<1	0 2	0 9	13 4	14	14	17	18 2	20 2
Ditto Menees and Holly (U.S.A.)	*	*										
Ditto Davies and Parsons (Britain)	0 6											
Epiphysis greater trochanter	2 7	4 4	3	5	4	6	14 4	15 10	14	16	16 10	17 6
Ditto Borovansky and Hnévkovský (Prague)		3 5										
Epiphysis lesser trochanter	9 0	8 11	14								16 10	17 11
Epiphysis distal femur	(262)	(263)	A.N.	A.N.	(280)	(283)	14	16	17	19	19	19
Ditto Pryor (U.S.A.)						3 days						
Ditto Menees and Holly (U.S.A.)					*	*						
Center for patella	2 6	3 11	2	5	3 0	8						
Ditto Borovansky and Hnévkovský		3 7										
Ditto Hellmer (Sweden)	1 11		4	5								
Center fabella	17	16 5										
Epiphysis proximal tibia	(294)	(294)			(324)	(334)	14	16	15	18	18	19
Ditto Menees and Holly (U.S.A.)			A.N.	A.N.								
Ditto Pryor (U.S.A.)					25 days							
Epiphysis proximal fibula	2 11	3 4	3	5	4	5	14	16	17	19	18	19 8
Epiphysis distal tibia	0 7	0 9	<1	<1			13	14 9	14	17	16 4	18
Ditto Borovansky and Hnévkovský (Prague)		0 3										
Epiphysis distal fibula	0 11	0 9	<1	<1	0 9	1 8	14 10	15	14	17	16 4	18
Center for calcaneus	(165)	(205)	A.N.	A.N.	(280)	(147)						
Apophysis of calcaneus	7 1	7 5	7	8	7 9	8 7	12 10	14 6	14	17	16	18
Ditto Borovansky and Hnévkovský (Prague)		6 2										
Center for talus	(180)	(205)	A.N.	A.N.	(280)	(224)						
Center for cuboid	(315)	(295)										
Ditto Pryor (U.S.A.)			A.N.	<1	25 days	13 days						
Center tarsal navicular	1 0	2 6	1	3	4 4	5						
Center first cuneiform	0 9	2 6	1	2	0 11	2 2						
Center second cuneiform	1 8	2 10	1	3	2 6	2 6						
Center third cuneiform	0 7	0 9	<1	<1	0 9	0 10						
Ditto Menees and Holly (U.S.A.)	*	*										
Epiphysis first metatarsal	2 0	2 6	2	3	2 4	3 6	14	15	14	17	18	18
Ditto Davies and Parsons	0 10											
Epiphysis second metatarsal	2 0	4 6	3	3	2 7	3 6	14	15 2	14	17	18	17
Epiphysis third metatarsal	2 0	4 6	3	3	2 7	3	14	15 2	14	17	18	17
Epiphysis fourth metatarsal	3 4	4 6	4	5	3 5	4 6	14	15 2	14	17	18	18
Epiphysis fifth metatarsal, distal	3 4	4 6	4	5	3 5	4 6	14	15 2	14	17	18	18
Epiphysis fifth metatarsal, base	12	13 4										
Ditto Borovansky and Hnévkovský		11 7										
Epiphysis proximal phalanx hallux	2 0	2 6	2	3	2 4	2 6	14	15	14	17	18	17
Ditto Davies and Parsons (Britain)	0 10											
Epiphysis proximal phalanx second toe	1 0	2 0	1	2	2 7	2 6	14	15	14	17	18	17
Epiphysis proximal phalanx third toe	1 0	2 0	1	2	2 7	2 6	14	15	14	17	18	17
Epiphysis proximal phalanx fourth toe	1 0	2 0	1	2	2 7	2 6	14	15	14	17	18	17
Epiphysis proximal phalanx fifth toe	2 0	2 6	2	3	2 7	2 6	14	15	14	17	18	16 6
Epiphysis middle phalanx second toe	2 0	3 5	2	3	3	9 8	12 10	15	15	17	18	16 6
Epiphysis middle phalanx third toe	1 0	2 0	1	5			6	16	6	13	18	16 6
Epiphysis middle phalanx fourth toe	2 0	2 0	2	5			6	16	6	13	13 6	16
Epiphysis middle phalanx fifth toe	2 4	2 0									13 6	12 1
Epiphysis distal phalanx hallux	1 0	1 9					13 0	15	15	17	18	16 6
Epiphysis distal phalanx second toe	6 6	5	6	5	3	8	12 10	15	13	15	18	16
Epiphysis distal phalanx third toe	3 11	5	3	5	3	8	12 10	15	13	15	18	16
Epiphysis distal phalanx fourth toe	3 11	4 0	3	5	3	8	12 10	15	15	15	18	16
Epiphysis distal phalanx fifth toe	3	3									13 8	16
Sesamoid head of hallux	9 7	12 5	13	12	11	11 2						

A.N. = Antenatal
P.N. = Postnatal
* = Within forty-eight hours after birth

uterine fetuses in roentgenograms taken before the fifth month, the following are significant and should be sought for:

Primary Centers.

Bodies of atlas, epistropheus, fifth sacral and first coccygeal segments.
Arches of third, fourth and fifth sacral vertebrae.
Three segments of lateral mass of sacrum.
Sternebrae.
Pubis.
Calcaneus, talus and cuboid.
Middle row of phalanges of toes.

Epiphyses.

Distal epiphysis of femur.
Proximal epiphysis of tibia.
Epiphysis for head of humerus.

Although apparently not yet recorded as having been encountered in the living intrauterine fetus, it is probable that in rare instances, the capitate, hamate and third

cuneiform may be demonstrated before birth.

If any of the above features can be identified, a study of the text and tables of this article should assist in arriving at an estimate of the period of gestation.

The foregoing tables are based upon actual observations only. The earlier ages at which ossification centers and epiphyses appear and fuse in the female is clearly evident. There are few exceptions, but some of these at least may be due to insufficient material for examination, but as these become more abundant, many apparent discrepancies will disappear and some of the gaps will be filled in at the same time.

In a number of instances, centers of ossification were noted very considerably beyond the range of the mass of those examined, and it is suggested that these might be caused by some abnormality of a pathological nature, perhaps of endocrine origin.

Wherever such have been available, ages have been given in months as well as in years, but where this is not done, the figures cannot be relied upon with the same degree of accuracy.

SUMMARY

1. A comprehensive survey of the time of appearance and fusion of centers of ossification and epiphyses by roentgenological means—as yet the most satisfactory method—has not yet been undertaken.

2. The figures usually given are exceedingly variable and generally incorrect, being frequently based on the methods prevailing before the advent of roentgenology.

3. It is of fundamental importance that an accurate conception of the normal periods of such be available before it is possible to appreciate any departure from the normal, such as might occur in endocrine dysfunction, or other pathological states.

4. Studies of the ossification in the human fetus of varying lengths from 30 mm. up to full time are made, described and tabulated.

5. Studies of the human skeleton in vivo from the date of birth until maturity are also made, described and tabulated.

6. Though some regions, such as the spine, are still incompletely studied, it is believed that this is the first attempt to study individually such bones as those of the hand and foot including the sesamoids. It is quite clear that the metacarpals, metatarsals and phalanges of the hand and foot do not as is usually described develop similarly in each row.

7. Such variations as inconsistency of appearance, asymmetry, irregularities in order of appearance and fusion, difference in the two sexes and in different races, etc., are given.

8. A center for the epiphyses of the symphysis pubis has not been satisfactorily demonstrated, likewise several others commonly accepted. Probably these do not exist.

9. A new undescribed os malleoli has been met with on both sides in one subject. It is believed that the separate center for the lateral mass of a sacralized lumbar vertebra has not been previously described. Cervical ribs have been demonstrated to be present in two fetuses.

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THE CLAVICULAR EPIPHYSES

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TWENTY FIGURES

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INTRODUCTION

Some years ago Doctor Stevenson published from this laboratory an account of the union of epiphyses in man(8). The most striking of the facts observed in the Reserve material was the practical uniformity in union during the nineteenth year of epiphyses of the long bones excepting those of the humerus. The epiphyses at the lower end of the humerus are already united at this age and the upper epiphysis unites in the twentieth year. These results are so different from the published accounts in textbooks and other current descriptions that it was apparent from the first that they would be assailed. Further this common property of uniting in the nineteenth year differentiates these epiphyses from others in clavicle, scapula, os innominatum, ribs and vertebrae. It suggests that there may be some distinction of significance which underlies this difference.

Naturally the theme first enunciated in Stevenson's work requires very full and extensive examination. Hence it was my original intention to carry on this work along three lines; examination of human skeletons, examination of mammalian skeletons, and lastly examination of living children by roentgenography and careful checking of ages. It was not possible for Stevenson in the course of a year to carry out this full program and I therefore suggested that he chart and publish our human material in advance. Naturally this article required certain comments of an editorial nature referring to the greater bulk of the investigation upon which I was then and still am engaged. The examination of adolescent mammals now covers nearly seven hundred specimens and the roentgenographic examination of children includes some eight hundred human beings. The effect of this mature investigation is to confirm thoroughly our original thesis. But before throwing open the complete collection of data to public discussion I am desirous of clearing up certain fundamental characteristics of an epiphysis which seem to be remarkably obscure. For this purpose the clavicle lends itself admirably and in the early history of this investigation I suggested to Stevenson that he would find the clue to many obscure facts in the two ends of this bone. Stevenson then discovered an ossified lateral epiphysis in the clavicles of two of our lemur skeletons, but he was unable, from lack of time, to continue the line of investigation.

Two years ago I asked Doctor Joseph D'Errico, Jr., to investigate the clavicle and we have now completed the work needed.

This article is written by the senior author who takes full responsibility for the form of presentation, but the original investigation has been jointly pursued by both authors except that distance caused the examination of the College of Surgeons material to be carried out by the senior author alone.

THE NATURE OF AN EPIPHYSIS

An epiphysis, it must be remembered, is a minor skeletal element and its precise composition, whether fibrous tissue, cartilage or bone is immaterial. In the mammalian body are to be found examples of every stage of composition from the fibro-cartilaginous to the fully ossified condition. We can speak of union of an epiphysis, strictly, in those instances only where ossification takes place and usually we refer, by this expression, to epiphyses which ossify entirely.

But union of an epiphysis implies something more than fusion of bone with bone. It means that an important stage of differentiation is terminated. Provided that the normal sequence of transformations occurs, all trace of distinction between epiphysis and major skeletal element disappears. But if, by any chance, some unusual, probably abnormal, factor is at work, scars remain although the essential phenomena may be carried out. We know very little about these factors which are certainly constitutional and seem to me to have some relation to diet or nutrition (see Harris 5). They have misled certain recent workers (Dawson 2, Harris 5) and are partly responsible for discrepancies between Pryor's work(7) and our own. But for so important a question fuller treatment is necessary than can be accorded here and hence I shall deal specifically with the problem in another communication. By far the greater number of limb epiphyses ossify completely and unite over the entire surface of contact with the larger bone. But there are certain epiphyses which sometimes ossify and sometimes do not, namely those of the second phalanges of the toes. And there are epiphyses which regularly ossify only in part, namely those of the clavicle and vertebral border of the scapula. The partially ossifying epiphyses of the clavicle are examples of a type widely spread throughout the body and, as such, have considerable significance in a comprehensive study of skeletal differentiation.

THE CLAVICLE A TRUE LIMB BONE

There is a widespread, and to my mind, quite erroneous notion that the clavicle differs fundamentally from all other limb bones; that whereas they are cartilage bones, it is a membrane bone. It is a fantastic theory based upon the failure to recognize the cartilaginous stage which is perfectly obvious. It has been noted in my earlier work(9) and more fully described by Fawcett(4). Certainly the clavicular cartilage differs somewhat from the cartilage of other bones, but similar distinctions in morphological features of the cartilaginous stage are by no means uncommon in the skeleton. Desperate endeavors of a previous generation to insist on a fundamental distinction for the clavicle and to identify the homology of this bone on the leg and in other forms of life should not blind us to the truth that the so-called fundamental distinctions are simply the outcome of insufficient observation.

SPECIAL FEATURES OF THE STERNAL END OF THE CLAVICLE

So far as the epiphysis of the sternal end of the clavicle is concerned, there are no marked differences in degree or in principle throughout the mammals, although in the rat a peculiar condition simulating but not really the sternal epiphysis seems to remain permanently(3). Man never reaches the stage of total failure of ossification although in some specimens the amount of ossification is very small.

By reason of change of texture in the end of the shaft adjoining the sternal epiphysis, a change which will be fully described in succeeding pages, the date which corresponds to epiphysial union can be readily ascertained. Therefore it is possible in our mammalian studies to list the time of union of the sternal epiphysis. In rodents the lateral extremity of the clavicle shows the change characteristic of union of the epiphysis, whether or not ossification of the epiphysis indeed occurs, slightly before the time of eruption of the third molar, a date when the distal epiphyses of the humerus are already united and that of the femoral head is commencing to fuse. These features are found in a specimen

of Anomalurus pelli no. A 3065 in the College of Surgeons Museum. We have ourselves a specimen of Echinops at practically the same stage in its life history, though as yet only the lesser trochanter of the femur has its epiphysis fused, and the third molar is worn slightly, with lateral clavicular epiphysis united. The lemur series shows it in a Hapalemur with the third molar just erupted and the median epicondyle of the humerus commencing to unite. In Semnopithecus maurus this clavicular stage is reached when the distal epiphysis for humerus and for coracoid alone are united. The phalangeal epiphyses in this specimen are not yet fused. It occurs in one of our Orangs when the epiphyses of the second phalanges have already begun to unite but before eruption of the third molar. Among marsupials again the phenomenon occurs at practically the same date for a Cook's Phalanger shows it just before union of distal humeral epiphyses but after closure of epiphyses on coracoid and phalanges while yet the fourth molar is not worn.

Union of the sternal epiphysis of the clavicle is found in Sciurus indicus before union of the distal epiphysis of the femur but later than union of the head, the third molar being not yet worn. It occurs at the same stage in Midas rosalia but is later in all other primates. There is a Perodicticus potto showing union of the sternal epiphysis just before fusion of the iliac crest when union of the vertebral scapular border is begun. The third molar is worn in this animal. But in an Orang, though all other epiphyses are fused the third molar is not yet erupted long enough to show wear. Among the marsupials we have observed this stage of clavicle history in a Wombat showing recent union of the humeral head.

Thus so far as Man is concerned union of the lateral epiphysis is a little later than in most mammals but fusion of the sternal epiphysis occurs at about the same relative date as in other mammals.

The relation of sternal end of clavicle to manubrium sterni is subject to much variation. In one of its forms the medial end of the clavicle comes to lie almost wholly behind the

manubrium. In individuals in whom this occurs the sterno-clavicular ligaments are so lax that, oftentimes, the clavicle can be lifted up out of its site behind the manubrium. This condition has been described by Cyriax(1) and has become incorporated in clinical literature as dorsal dislocation. The clinical definition is entirely erroneous as to cause but exact enough in its indication of effect. For quite frequently the result is just what one would expect of a dorsal dislocation. And, indeed, some trauma may greatly exaggerate the otherwise imperceptible consequences of the condition.

THE STERNAL EPIPHYSIS OF THE CLAVICLE

Figure 1 shows the sternal ends of the shafts of a pair of typical clavicles. They belong to no. 1012 a female Negro of eighteen years. Ossification has occurred in the epiphyses and the ossifying epiphysis has been left in situ on the right bone but removed from the left. It is unusual to find ossification so far advanced at eighteen years but, as I have frequently insisted, the date of commencing ossification is unimportant. This pair serves as an example of the practically plane sternal end.

Figure 2 shows the sternal ends of a pair of clavicles which illustrates the convex type. It is no. 644, female, White, twenty years.

Then follows the sigmoid contour typified by figure 3, the sternal ends of clavicles from no. 233 a male White of nineteen years.

The type of texture common to all three but most clearly expressed in no. 233 is characteristic of the end of a shaft before union with the epiphysis. The phrase union of epiphysis is employed in the more fundamental sense of termination of the stage of differentiation which, in the instances of which we usually think, is accompanied by final fusion of the ossified epiphysis with the shaft. It is common to all bony surfaces overlaid by an ununited epiphysis and is equally apparent in such widely differing areas as the upper end of the humeral shaft, the symphysis pubis, and the back of the

calcaneus. The surface is finely granular and coral-like. Upon it are numerous depressions, some rounded, some mean-

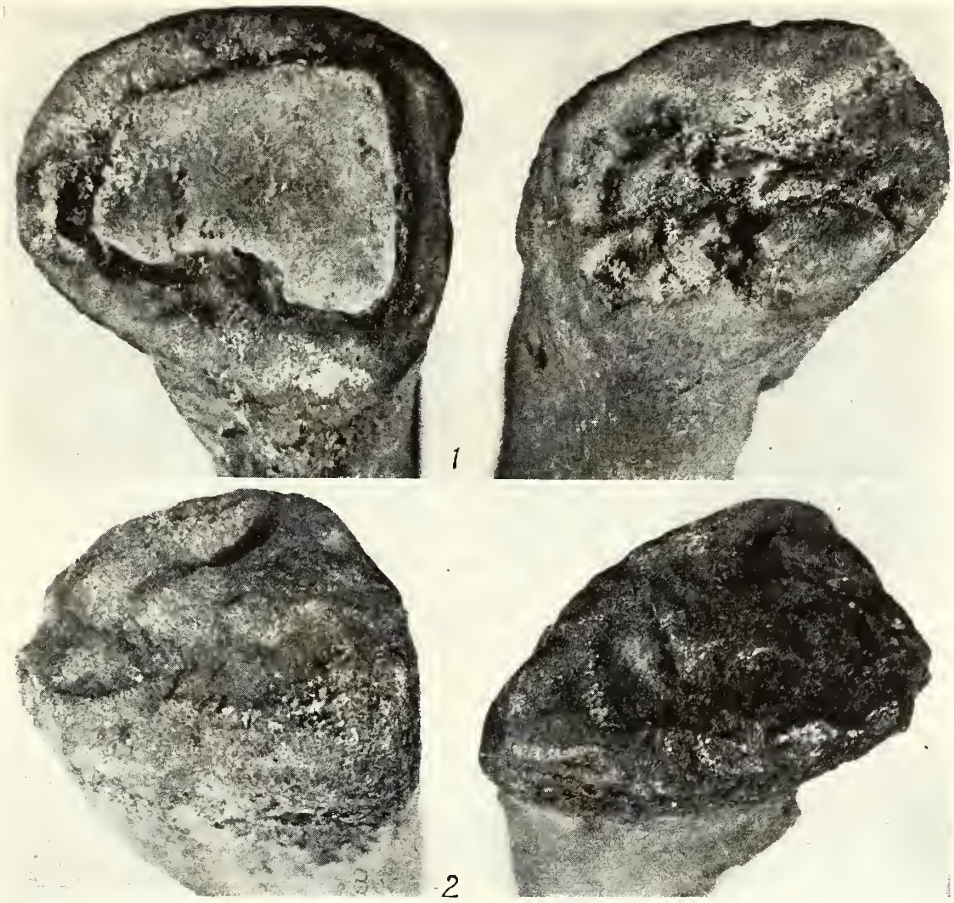

Fig. 1 Sternal ends of clavicles. No. 1012, female, Negro, 18 years. Plane type.

(In this and all succeeding figures the subcutaneous surfaces of the clavicles are placed face to face so that the right bone is to the left of the figure and the left bone on the right).

Ossifying epiphysis removed from left bone. Note the close waxy texture of the right epiphysis and the grained coral-like texture of the left shaft end. The grooves are vascular in origin.

Fig. 2 Sternal ends of clavicles. No. 644, female, White, 20 years. Convex type. Again note coral-like texture of naked shaft ends with vascular grooves characteristic of growing bone.

dering without apparent design. They are vascular in origin and disappear with the termination of growth at this site. There are many, apparently individual, modifications of this

texture but they are unimportant. I have divided them into finely and coarsely textured varieties, the former more usual in Whites, the latter more frequent in Negroes(10). But I was unaware of the exceedingly fine texture characteristic of the Mongolian Stock until Professor Sasaki showed me the result of his observations at Kumomato. This difference in degree of the vascular grooves and pits is apt to be misleading until a careful study of texture has enabled the investigator to distinguish between the coral-like appearance of the growing shaft and the waxy aspect of the completed bone.

Figure 1 is intended to emphasize this distinction. The epiphysis, as it ossifies, becomes transformed into a bone of much closer texture, totally unlike the surface of the shaft which it is covering. This close and waxy texture is characteristic of entirely quiescent bone. It is found at articular ends, on the surface of the cranial vault, on the face, the neural arches of vertebrae, the blades of scapulae and ossa innominata, on the greater part of the carpals and tarsals and on those parts of the long bones and ribs which are perfectly quiescent and undergoing no change whatsoever.

The surface texture characteristic of that form of sternal end which is so deeply excavated that it tends to slip behind the sternum, is shown in figure 4, the clavicles from no. 410 male, White, eighteen years. In spite of a texture more finely grained than in no. 233 (fig. 3) but nevertheless more characteristic of White Stock, these surfaces are quite obviously those of a growing shaft with the vascular surface channels plainly marked. Why the deep excavation should occur we have never been able to discover.

It is quite a striking fact that marked excavation of the clavicle interferes in no way with the typical life history of the sternal epiphysis. Figure 5 illustrates this very well. Here are the clavicles from no. 1228, male, White, twenty years. The epiphyses have already begun to ossify and the new bone is creased and crinkled following the irregular outline of the deep excavation. It is still lying free in the deep pit but held in place like a walnut in its shell.

It is then justifiable to conclude that no modification whatever of the sternal end of the clavicle interferes at all with the typical appearance of the texture at the end of the shaft or with the life history of the epiphysis.

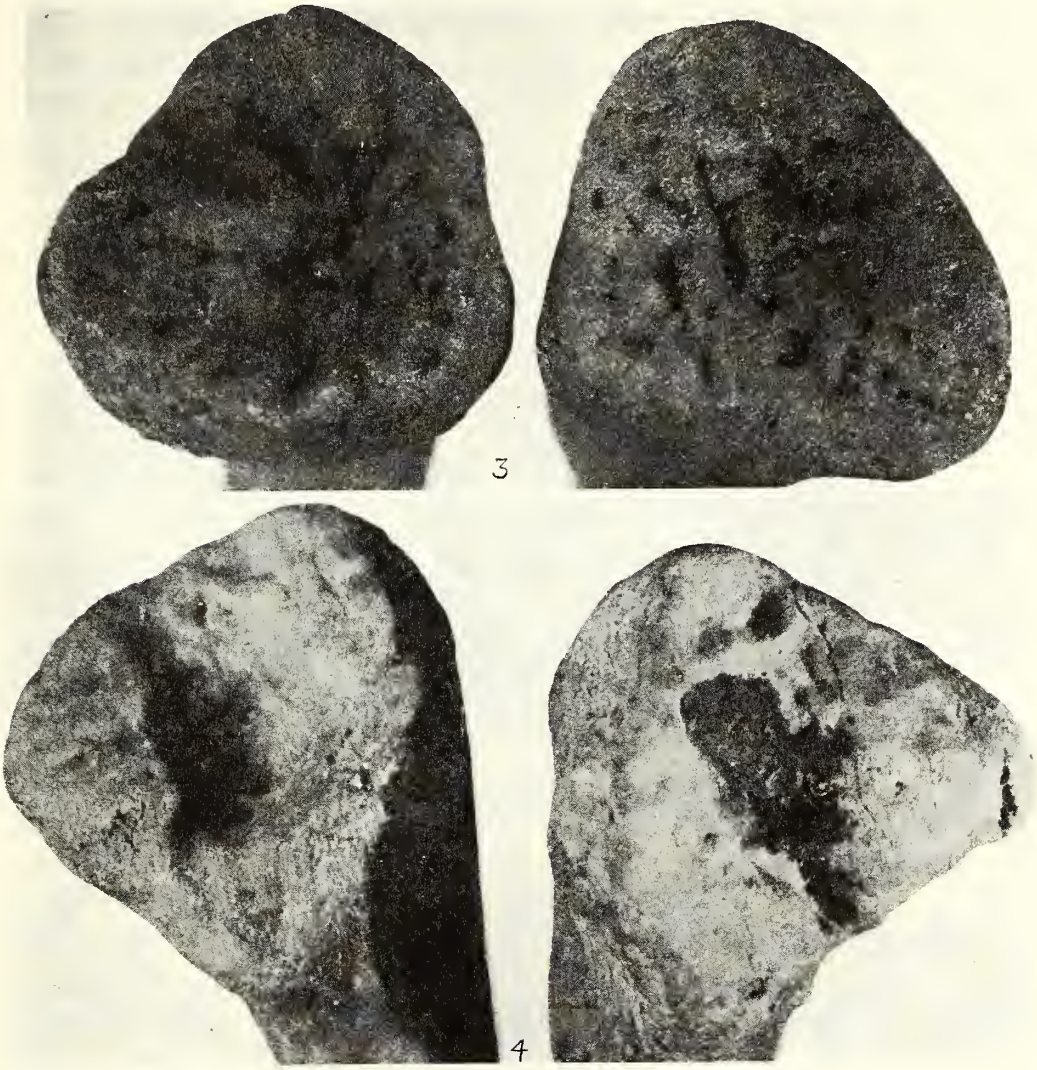

Fig. 3 Sternal ends of clavicles. No. 233, male, White, 19 years. Sigmoid type. The coral-like texture is even better marked in this specimen because the grain is coarser and the vascular grooves are better marked.

Fig. 4 Sternal ends of clavicles. No. 410, male, White, 18 years. Concave type. This is a finely granular texture: the vascular grooves are somewhat deformed by the marked excavation.

UNION OF THE STERNAL EPIPHYSIS

The epiphysis ossifies over a greater or less extent of its bulk. Sometimes part of the shaft end is left bare of epiphysial bone. But in the course of time the now bony epiphysis unites with the shaft. The epiphysial bone is of a very finely grained waxy texture and has been sufficiently described. Where the epiphysis does not ossify, the shaft, left bare and naked, does not preserve indefinitely its coral-like

Fig. 5 Sternal ends of clavicles. No. 1228, male, White, 20 years. Concave type. Ossification is occurring in the epiphysis which is deformed but not otherwise affected by the excavation.

texture but, at the date of 'union,' glazes its surface with the same waxy bone as that which grows in the epiphysis itself. Therefore in an adult bone it is sometimes quite difficult to decide whether one is looking at an epiphysis-covered extremity or merely at a shaft-end over which has been poured that deposit of glazed new bone comparable with and indistinguishable from epiphysial bone.

As for the date of first ossification of the epiphysis, there is no practical significance in that. Nature is quite unconcerned over this as she is over the date of commencing ossi-

fication in carpals and tarsals. So we shall make no endeavor to describe the vagaries of this process. Much time and effort have been expended in attempts to wrest some connected story out of the progress of carpal ossification. It is futile to pursue that study further, at least by methods hitherto developed. But epiphyseal union is another problem altogether. Both Stevenson and I have sought to distinguish between these two phenomena(8) which are so intimately related in existing descriptions. There is no inherent reason why there should be a relation between the commencement of ossification in an epiphysis, a process which is entirely dependent on factors in the epiphysis itself, and the termination of growth at the end of a shaft which is a phenomenon of the general growth of the body. Whereas shaft dimensions are most variable, epiphysial dimensions are most constant (Ingalls 6).

When Stevenson made the initial complete survey of our adolescent material he had fifty skeletons of known age between twenty-one and twenty-seven years inclusive. When D'Errico made his survey this number had increased to one hundred and two, distributed thus: male White, 32, female White 7, male Negro, 52, female Negro 11. We did not think it worth while to subdivide Stevenson's fifty skeletons although we could distinguish no sexual or racial differences. Now we have separated both sex and race and our earlier conclusions are abundantly confirmed.

It is inevitable that two men working over so large a material as the Reserve collection of human skeletons should make lists differing slightly the one from the other. Occasionally later information upon a skeleton would add to or detract from the conviction that the recorded age was accurate. Of course no data based on the clavicle itself can be admitted in solution of such a problem. Hence Stevenson's list and D'Errico's selection from the lower ranges of the series are not exactly the same. The skeletons used are all carefully inscribed on the charts and the discrepancies can be readily noted. Stevenson's figure is reproduced here as figure 6 so

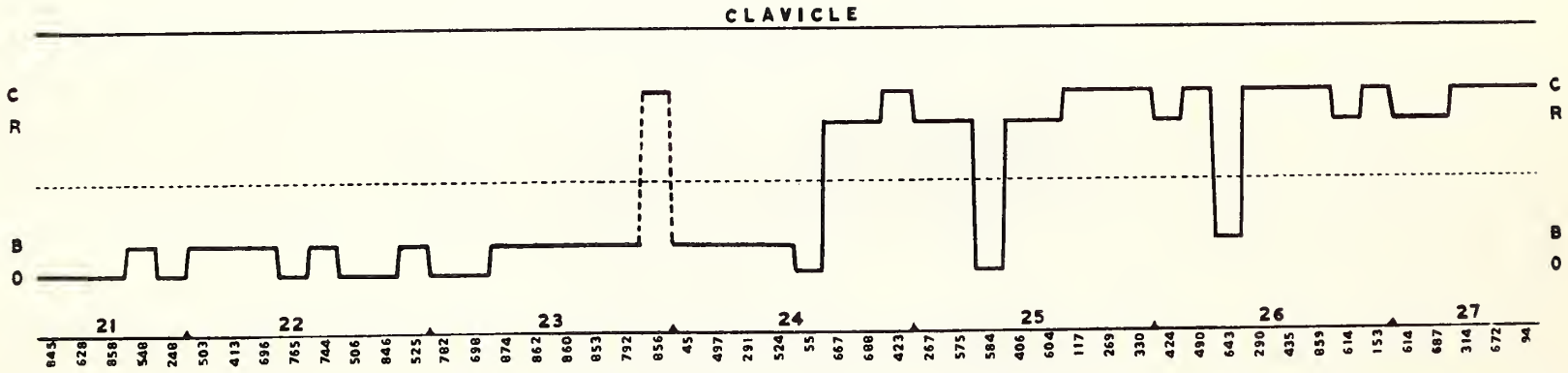

Fig. 6 Stevenson's chart of union. Sternal epiphysis of clavicle. Abscissae: C. complete union. R. recent union with scar. Broken line: distinction between union and non-union. B. beginning union. O. no union. Ages in years. Ordinates: skeletons by number.

that it may be compared with the later charts of D'Errico (figs. 7, 8).

In all charts there is a uniformity which is very striking. In both sexes and both races union of the sternal epiphysis is practically completed in the twenty-fifth year (R). The main discrepancy between Stevenson and D'Errico is in skeletons 667 and 688. The former observer considers that union has progressed further (R) in these epiphyses than the latter would admit (B). That is a matter of opinion. The ossifying

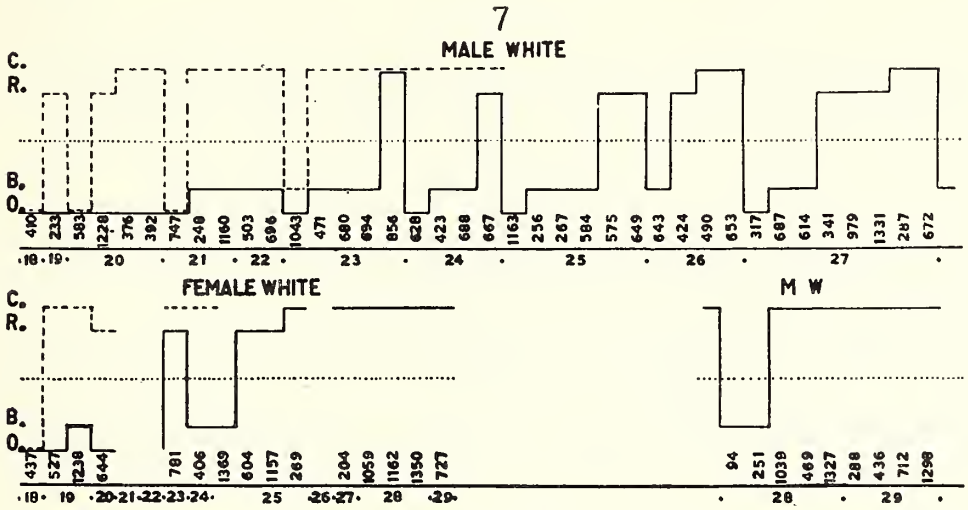

Fig. 7 D'Errico's chart of union. Epiphyses of clavicle. White Stock, male and female. Abscissae and ordinates as in figure 6. Solid line: sternal epiphysis. Broken line: lateral epiphysis.

epiphysis, with rare exceptions, begins to unite in the twenty-first year but practical completion of union (R) does not take place till four years later. The loss of all trace of the site of union (C) quickly follows. Of course there are exceptions, mainly in the four years centering on twenty-five. It is not worth while discussing these anomalies in detail here. I have already touched upon the subject in my work on the symphysis pubis(10). The fact that anomalies occur, especially since they usually result in an insignificant retardation or acceleration of a year or two, is in no way disharmonious with the enunciation of a general principle. Facts have been

adduced by Harris and Dawson from studies on the hedgehog and the rat, seeming to clash with our general principle. I do not think Harris can have had adult hedgehog material for there are many skeletons of this beast in the College of Surgeons showing complete fusion of humeral and femoral epiphysis. Dawson works almost entirely with a domesti-

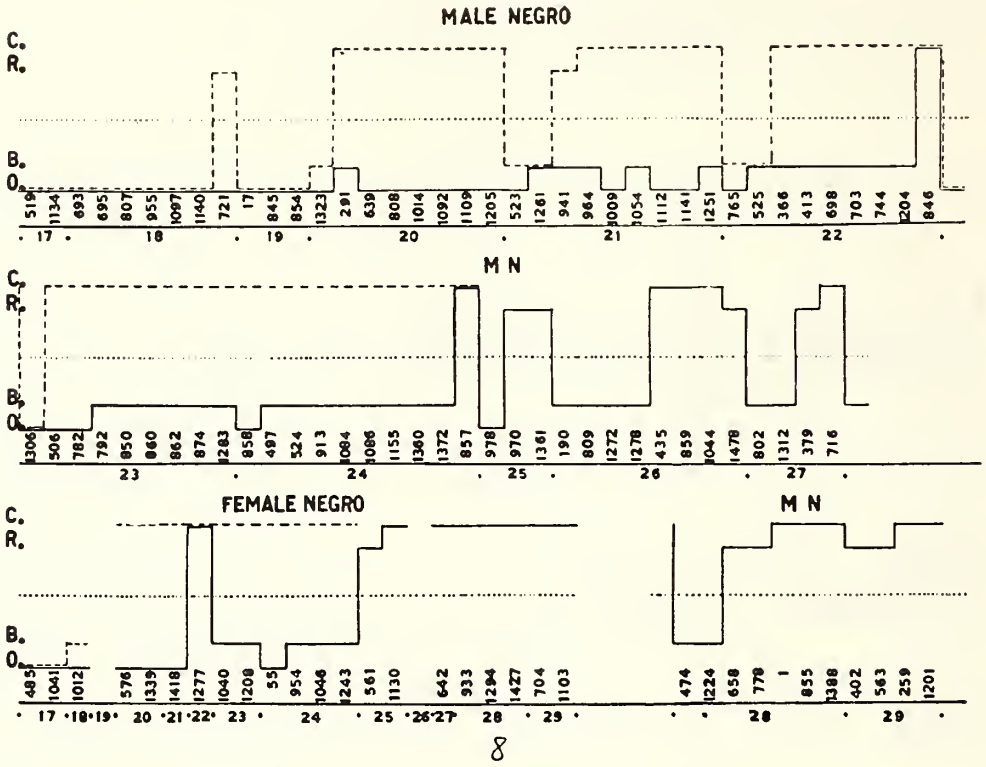

Fig. 8 D'Errico's chart of union. Epiphyses of clavicle. Negro stock, male and female. Abscissae and ordinates as in figure 6. Solid line: sternal epiphysis. Broken line: lateral epiphysis.

cated stock of rats. In this he has shown evidence which to my mind is evidence of anomalous, even pathological lapsed union in the diaphyso-epiphysial planes of humerus and femur. We see it also and I am at present engaged on an article for the more effective presentation of this phenomenon. But a large collection of normal wild rats, like that of the College of Surgeons, shows complete union of these epiphyses.

If we seem to brush aside too lightly the perfectly sincere observations made by investigators who disagree with the principles of epiphysial union enunciated from Reserve, it is not that we minimize their results or discredit their method. The problem of defect in epiphysial union is a large one and requires special treatment. For the moment we must ask the reader to have patience and permit us to develop still further the thesis we have already put forward in Stevenson's article. It is characteristic of limb epiphyses to carry the process rapidly to completion once they have started to unite. The entire progress occupies less than a year. But at the sternal end of the clavicle the progress, shown in the charts, appears to take much more than a year. There are however many anomalies. And in addition the charts show no intermediate stages between beginning and recent union. From this it is to be understood that further intermediate stages are not easily identified. Although progress is certainly somewhat slower in the sternal end of the clavicle than it is, say, at the shoulder or wrist, yet it is not very markedly slower. The epiphyses at the knee are intermediate in type. The real explanation is that there is much individual variation in the date of commencing union and the process, once begun, progresses slowly, taking two or three years instead of one to complete the union. But this is not in any way comparable with the practical prohibition of further union in the animals studied by Dawson. As for the real reason for delay in progress of union at the sternal end of the clavicle compared say with union at the upper end of the humerus, that remains as obscure as ever.

THE LATERAL EPIPHYSIS OF THE CLAVICLE

The lateral extremity of the clavicle is not usually accredited with an epiphysis though occasionally one finds an anatomist who admits its rare occurrence. (Cameron acknowledges it but does not mention it in his book). If it were indeed true that there is no epiphysis at this site, the clavicle would be unique among the long bones of the limbs.

But it is not true. What is really meant is that there is only rarely an ossification in the lateral epiphysis of the clavicle. We may well inquire then what happens when the epiphysial cartilage develops no bony nodule. As a matter of fact most lateral clavicular epiphyses do develop bony nodules but they are often rudimentary, and in conformity with the general rule that fusion occurs quite rapidly once it starts, the small bony nodule almost at once fuses with the shaft and loses its separate identity. But should there be no bony nodule developed, the epiphysial cartilage nonetheless disappears and the end of the shaft becomes glazed over with a waxy textured bone, simulating quite exactly a united epiphysis.

Therefore it is not difficult to tell from the macerated clavicle whether or not 'union' of the epiphysis has occurred. D'Errico's charts show the date of 'union' of the lateral epiphysis by a broken line. It is not included at all on Stevenson's chart for the full story of this epiphysis was not known at that time. Like the majority of the long bone epiphyses, union takes place during the nineteenth year. Occasionally it is postponed to early in the twentieth or even rarely a year or so later. Such instances are however anomalies and do not affect the general rule.

Now ossification in this epiphysis occurs very late if at all and within a few months of the first appearance of epiphysial bone the epiphysis is united to the shaft. Consequently it is a rare thing to find this epiphysis in process of union. It is by no means common to obtain a skeleton in which the other limb bone epiphyses are actually uniting, that is if one except skeletons in which the two epiphyses at the distal end of the humerus are united and the rest not. But, infrequent as this is, the occurrence of a skeleton with an actually uniting lateral clavicular epiphysis is so much rarer still that we had macerated 1228 bodies before we discovered the one which we needed to put the final stamp of authority on this research. In an investigation of more than two hundred adolescent mammalian skeletons in the Reserve collection we have found two examples only. The search through collections in several

of the main Museums of America and through that of the College of Surgeons failed to disclose a single specimen. So rare is it to strike a lateral clavicular epiphysis in process of union.

This key specimen no. 1228 is a male White of twenty years (fig. 9). On each lateral face can clearly be seen the bony epiphysis recently united and the waxy fine textured bone

Fig. 9 Lateral epiphysis of clavicle. No. 1228, male, White, 20 years. Unusually high degree of ossification in epiphysis. Recent union, waxy texture of epiphysial bone and of glaze on naked end of shaft.

characteristic both of an epiphysis and of the quiescent shaft end. The right epiphysis has ossified more than the left.

It is our custom to make roentgenograms of every clavicle between eighteen and twenty-eight years so that we may know the extent of ossification of the epiphyses previous to maceration. The many scores of roentgenograms we have taken have however yielded nothing comparable with this pair for it is an extremely rare thing to find so much ossifica-

tion in this epiphysis (fig. 10). Nevertheless the fortunate accident which gave this specimen into our hands has enabled us to demonstrate beyond all question the truth of one of our main theses, namely that an epiphysis need not necessarily ossify. And if it does, the date and amount of ossification bear no relation to epiphysial union or, as we would prefer to express it, to the termination of the growth phase in the shaft.

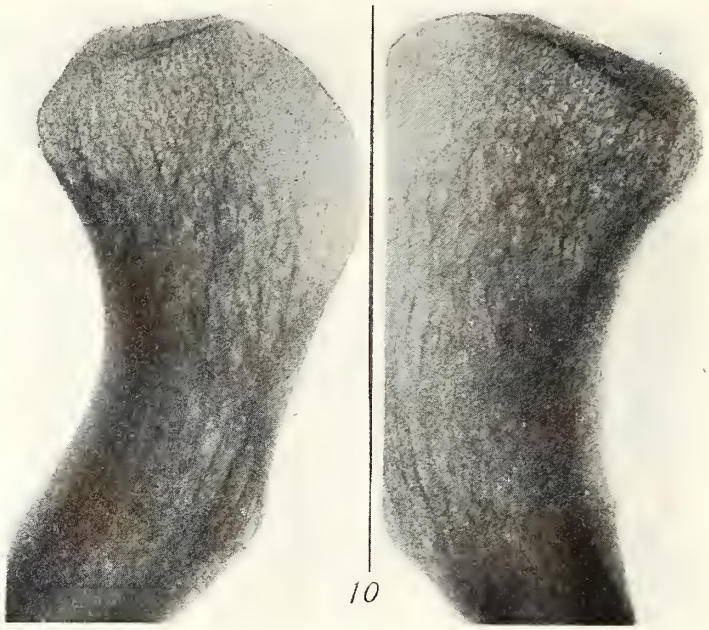

Fig. 10 Roentgenograms of lateral epiphyses of clavicle. No. 1228, male, White, 20 years. Epiphysial ossification clearly shown on both bones.

The two mammalian examples were both found in the Lemuridae, the one in Loris tardigradus Linnaeus B. 750 and the other in Perodicticus potto. E. Geoffroy B. 751 (fig. 11).

The stage of epiphysial union in Loris B. 750 is thus defined. M3 is not worn. Basilar suture not fused. Metacarpals and metatarsals recently united. Humeral head; distal radius, ulna and femur; both epiphyses of tibia and fibula; vertebral border and angle of scapula; iliac crest and ischial tuber all ununited but other epiphyses on these bones save the os innominatum are all fused.

In Perodicticus B. 751 (fig. 12) the stage of epiphysial union is practically the same but there is commencing union of the distal epiphyses of tibia and fibula and no union of metacarpals and metatarsals.

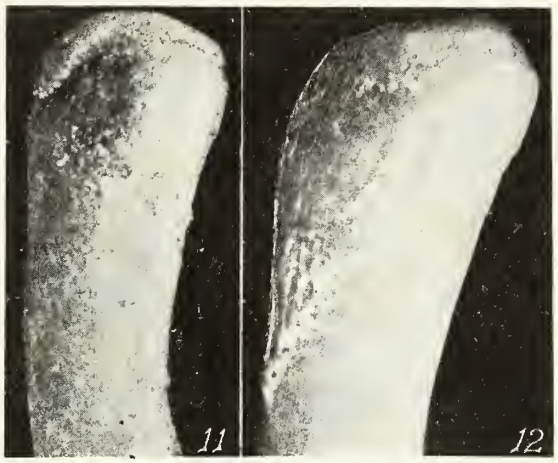

Fig. 11 Left clavicle. Loris tardigradus, W. R. U. 9.814-3, B. 750. Recent union of fully ossified epiphysis. Note mouths of vascular channels at line of union.

Fig. 12 Left clavicle. Perodicticus potto, W. R. U. 9.814-4, B. 751. Incomplete ossification of epiphysis. Beginning union. There is still shrunken dried epiphysial cartilage around the epiphysial bone.

Fig. 13 Naked lateral ends of clavicle. No. 410, male, White, 18 years. Note characteristic coral-like granular texture with vascular grooves.

There is more ossification in the epiphysis of Loris than in that of Perodicticus and the stage of union is a little more advanced.

Scanty as the evidence is, and perhaps its very scantiness is an asset, it shows definitely that there is a rudimentary ossification in the epiphysis, common to Primates, and that this ossification and the final union take place at the same stage of the life period no matter in what animal they are

Fig. 14 Naked lateral ends of clavicle. No. 807, male, Negro, 18 years. Compare with figure 13.

studied. I have already presented a bare sketch of the date in the epiphysial life history of other mammals.

With these facts in mind it is now possible to study appreciatively the less marked examples of 'union' at the lateral clavicular extremity.

We first present two specimens of the end of the shaft before there is any attempt at union. These are figures 13, 14, respectively. Nos. 410, male White eighteen years and 807 male, Negro, eighteen years. There are individual dif-

ferences between these but both present the typical coral-like texture and deep vascular grooves. Nos. 410 and 807 are typical and their stage is recognized at a glance.

Fig. 15 Uniting lateral epiphysis of clavicle. No. 765, male, Negro, 19 years. Note the white waxy epiphysial bone (A) fused on to the characteristic granular face of the naked shaft.

Fig. 16 'Uniting' lateral epiphysis of clavicle. No. 1012, female, Negro, 18 years. Granular texture of shaft is becoming glazed. There is no real ossification of epiphysis in this specimen.

Following these are three examples of the earlier stage of union and incidentally of ossification also. No. 765 male, Negro, nineteen years (fig. 15) shows the same features as the last but has a small nodule of new bone forming and uniting immediately.

No. 1012 female, Negro, eighteen years (fig. 16) shows something of the billowy appearance of the symphysial face of the pubis at a similar stage as the result of the pattern of

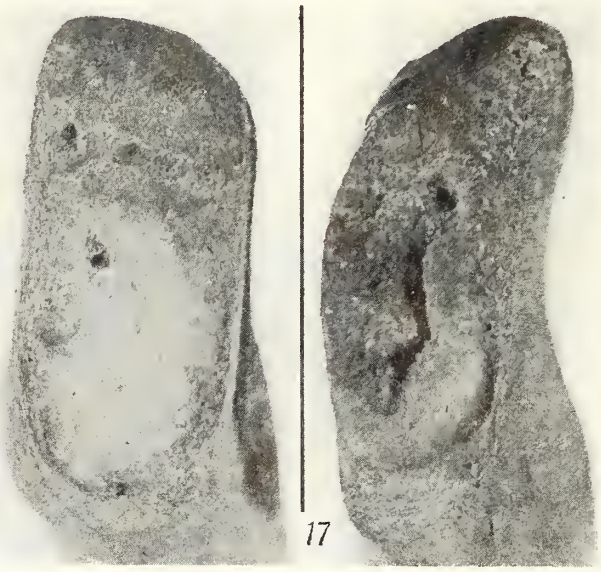

Fig. 17 Recently united lateral epiphysis of left clavicle. Completely united right epiphysis. No. 1043, male, White, 23 years. The partially ossified left epiphysis brings out the contrast of the waxy epiphysial bone with the coral-like granular texture of the shaft end. The completely united left epiphysis shows simply waxy texture.

vascular grooves. The finer quiescent texture is apparent round the margins. The diversity in shape of the shaft end is well exemplified in this series and is emphasized in the next group.

No. 1043, male, White, twenty-three years (fig. 17) is an aberrant specimen in which there is such a difference in appearance between the clavicles of the two sides that one would hardly accept them as belonging to a single skeleton were it not for the meticulous care in our skeleton prepara-

tion and other intrinsic evidence of the bones themselves. The right clavicle shows complete 'union,' the left is but beginning and has quite a large bony nodule recently united.

Then there are three further specimens, exemplifying recent union. No. 233 male, White, nineteen years (fig. 18) has

Fig. 18 Recently 'united' lateral epiphysis of clavicle. No. 233, male, White, 19 years. Vestiges of vascular grooves as yet incompletely glazed by waxy bone. There was no true epiphysial ossification in this specimen.

Fig. 19 Recently 'united' lateral epiphysis of clavicle. No. 644, female, White, 20 years. The waxy epiphysial ossification does not completely cover the shaft end.

no epiphysial bone but the glazing of the shaft end is almost complete and is scarcely broken by two or three remaining vascular grooves.

No. 644 female, White, twenty years, (fig. 19) again shows the glazed appearance of the quiescent bone. There is some slight ossification of the epiphysis here and it leaves its mark in the groove at its edge.

No. 721, male, Negro, eighteen years (fig. 20) is a specimen with excavation of the acromial end similar to the much

Fig. 20 Acromial excavation glazed by recent 'union' of lateral epiphysis. No. 721, male, Negro, 18 years. Unusually early completion of glazing.

more frequent excavation at the sternal end. Nevertheless the glazed texture signifies that the bone is quiescent and the stage is that of recent union for there is still some indication of incompleteness of the process.

The specimens figured have naturally been chosen for diversity both in appearance and date of union and must not be permitted to give the reader the impression that diversity is the rule and uniformity the exception. The true situation faces the other way: uniformity is surprisingly great, but it is essential that the investigator train himself in the little

understood fundamentals of skeletal texture and differentiation if he is to read correctly the story which then lies plain in every bone.

SUMMARY

1. An epiphysis is a minor element of the skeleton which may or may not ossify. If it does ossify, the transformation into bone may be complete or incomplete. Union of an epiphysis can only take place if ossification has occurred. Whether or not this has happened there is a stage in the life history of the shaft when growth ceases. This is usually the moment of epiphysial union. But if ossification has not occurred, or in the sites where it is incomplete, the epiphysial cartilage disappears and the same waxy textured bone which is typical of the epiphysis glazes over the naked end of the shaft. Such phenomena need not necessarily follow termination of growth.

2. The sternal epiphysis does not always completely ossify and hence often forms an example of the type just described. Marked excavation of the sternal end ('posterior dislocation') has no influence upon the character of the sternal epiphysis except to modify its shape.

3. The clavicle is a true limb bone forming in cartilage with an epiphysis at both ends.

4. The sternal epiphysis commences to unite about the twenty first or twenty second year and progress is slower than in other epiphyses, complete union not taking place till the twenty fifth year. It is not yet clear why there should be this retardation of progress. Anomalies occur, as elsewhere, of retardation or acceleration of not more than two years in date of union.

5. The lateral epiphysis of the clavicle ossifies and unites in the twentieth year, barring anomalies. If there is no ossification the glazing of the shaft end occurs at this date.

6. No significant sexual differences are found in union of either epiphysis and there are no distinctions which differentiate White from Negro Stock.

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CRITICAL COMMENTS ON METAMORPHOSIS OF BONES OF PELVIC AND SHOULDER GIRDLES

Inspired by the large number of documented skeletons which he had assembled at Western Reserve University, Todd was led to undertake, and to induce others to undertake, studies on age changes in human skeletons. The symphysial surface of the pubis was one of the first articular areas studied and seems to have given rise to the concept of bone metamorphosis as contrasted with actual growth, particularly after the age of 18. Although only the first of Todd's series of 6 studies on the pubis is here reprinted, since it contains the basic ideas, the others are recommended for further profitable reading. They are:

II. The pubis of the male Negro-White hybrid. Am. J. Phys. Anthrop., vol. 4, 1921, pp. 1-26.

III. The pubis of the white female. Ibid., pp. 26-40.

IV. The pubis of the female Negro-White hybrid. Ibid., pp. 40-70.

V. Mammalian pubic metamorphosis. Ibid., pp. 333-406.

VI. The interpretation of variations in the symphysial area. Ibid., pp. 407-424.

There has been some prejudice against Graves' work (although it was sponsored by Todd) on account of his inordinate interest in the shape of the vertebral border of the scapula. Yet his small paper on the metamorphosis of the scapula reprinted here contains about all that is known of this subject. It is regretable that he did not go beyond his preliminary note and fix more exact dates to the sequence of modification. As it is, considerable experience is needed to interpret and apply his descriptions. Eventually, when W. Montague Cobb publishes the results of his examination of the Todd and Terry collections, the whole subject of bone metamorphosis will be on sounder ground.

There remains to mention that one of the editors (T.D.S.) recently has studied the metamorphosis of the joints of the sternum. A paper on this subject will appear in the American Journal of Physical Anthropology.

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AGE CHANGES IN THE PUBIC BONE

I. The Male White Pubis

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Introduction

Everyone who has investigated series of skeletons, whether collections of modern necropolis material or of archeological importance, has felt the great lack of data upon which some reliable estimate of individual age may be based. This same lack is felt also in cases of medico-legal importance and in those which come under the control of the coroner long after all superficial and currently utilized signs of precise age have disappeared through decay. We are able, by examination of diaphyso-epiphysial junctions to make a fairly accurate estimate of age up to the commencement of adult life. Again we are

able to identify with some assurance the onset of senility. But for the vast proportion of skeletons or bodies examined, namely those between 25 and 55, we have no reliable criteria of age and can make only the most hazardous guess even after long experience because experience without accurate data can result only in a quite general "appreciation" of age.

The laws of Ohio permit the retention of material in the Anatomical Laboratory for an indefinite period and the Civic and Hospital connections of the Medical School and Anatomical Department render comparatively easy the accumulation of precise clinical data regarding most of the material used. In view then of the unusual opportunity offered for a study of osteology, we began, some eight years ago, to collect a series of skeletons with as full records as time and systematic organization permit. Naturally the outbreak of War, occurring just as our methods were becoming perfected, interfered considerably with the work. But with the return of the staff and the consequent rehabilitation of the laboratory during 1919 the investigation has now assumed its fullest proportions. Hence a few words as to organization may not be out of place.

Each cadaver upon arrival in the laboratory is weighed and has its anthropometric measurements recorded. Specimens of hair and skin for color determination and fuller investigation are secured from eleven typical areas. The family record is obtained from the City Hall archives and the clinical history from the Hospital files in every case where these are extant. After measurements of the vertebral column and pelvis have been taken in the recent state the entire skeleton is finally macerated and preserved by methods which need not here be entered into. The prepared skeleton, housed in its own box, is then passed on to the osteological library where every bone has marked upon it in Indian ink the admission number of the cadaver. Although time consuming this technical detail is essential, for the entire skeleton must be readily identifiable and kept intact. A short description of the skeleton is then made and the established age checked up with the bony features. The record is filed with the family, clinical and anthropometric data, together with all photographs which have been taken during the course of the work. Pathological features also are noted and filed. When the whole procedure has been carried out the skeleton is ready for any systematic study. In order to eliminate personal errors, all routine measurements and reports are made by a single individual. The total number of skeletons now prepared

and upon which data are filed is about 650 and increases at about the rate of 100 a year.

In systematic work of this kind numbers are essential and disappointment regarding records are not infrequent. Also complete breakdown of part of the work, such as the anthropometric investigation, could not be avoided during the later years of the War. Nevertheless the writer now feels in a position to produce data of sufficent exactitude to warrant publication, and the first effort will be to set forth the observations on age characters which this wealth of material permits.

The material consists of skeletons of male and female Whites, both American and foreign born, and of male and female Negroes. The majority of the latter are naturally not of full African descent but have a varying admixture of European blood, upon which admixture it is hoped the skin and hair samples will be found to have some bearing when these are fully investigated. Such skeletons are therefore referred to in our investigations as negro-hybrids.

Skeletal Age Changes in General

In the investigation of large series of human skeletons various modifications of the bones are met with which hitherto have not been accurately checked up against the age. Many of these modifications which appear successively during adult age are on the border-line between the anatomical and the pathological. Some cannot be so regarded, but must be classed as purely anatomical changes. Those upon which attention has been concentrated so far and which therefore must be dealt with in the course of the more immediate studies are: condition of teeth; closure of cranial sutures, both ectocranial and endocranial; occurrence of lipping on limb bones; ossification of costal cartilages; spondylitis as distinct from arthritis of the vertebral column; and changes in bony texture. In addition it has been found that certain bone areas adjacent to joints show definite sequence of modification strictly associated with age. In the main this group consists of amphiarthroses, namely the symphysis pubis, the intercentral joints of the vertebral column, and the manubrio-gladiolar articulation. But to these must also be added the sterno-clavicular, sacro-iliac and possibly the costo-chondral and chondro-sternal joints. The plane between the bone and the articular cartilage of these joints displays features resembling in some degree those of the diaphyso-epiphysial plane, and it is upon this fact that the age changes resolve themselves.

Adjacent to these joints 'articular' epiphyses ossify incompletely, erratically or not at all. Of the series the sterno-clavicular area early removes itself from consideration through the fusion of the epiphysis at the sternal end of the clavicle with the shaft of the bone, while the manubrio-gladiolar articulation is so erratic as apparently to warrant no confidence. The intercentral joints of the vertebral column, and the pelvic articulation areas, on the other hand, are most important. Even after the last stragglers among the epiphyses, namely those of the spines and transverse processes of the vertebrae, the heads of the ribs, and the sternal end of the clavicle, have lost their identity through fusion, the line of union of the central epiphyses shows distinct independence from the vertebral body. And when the second of these also at last, in the early thirties, fails to register the individual's age, the symphysis pubis still retains its role of time marker. Indeed the symphysis tells its tale throughout life, although less clearly from forty years onward than at an earlier age.

It is this prime importance of the symphysis as an age indicator which calls for its description first of all the age features.

No individual part of the skeleton however is infallible, and the most accurate estimate of age can only be made after examination of the entire skeleton. In the ensuing pages cases will be noted in which the symphysis lags behind or runs ahead of the rest of the skeleton in its development. But these instances are comparatively rare and cannot vitiate the main contention of the paper. According to our experience the symphysis, once its changing features are properly understood, forms one of the most stable and satisfactory guides to the age of the individual. But it is a relatively delicate bone and is often missing in skeletons which have lain for centuries in the earth, or is so badly damaged as to be of no value in age estimation. Hence it is necessary also to cast about for other more durable bony features and check them up against the symphysis upon our dated material. The comparative value of the several age indicators will be appraised in a later publication. Meantime it is well to bear in mind that the skeleton does not become adult in the sense that it shows no further gross changes of form or texture, at the age of twenty-five. Just as its histological structure is ever changing, so also are the naked eye features of the skeleton undergoing constant metamorphosis.

The Age Factor in Anthropology

In most anthropological work the extreme difficulty of the age question scarcely obtrudes itself. The integument with its accessories, especially the hair, has been the feature most generally utilized in checking up the stated age of an individual. Though important, the skin does not act as a very sensitive time marker and hence there is usually no stimulus in the investigator's mind to question the stated age of the individual in front of him, unless a very pronounced discrepancy exists. In consequence the difficulty of getting precise and reliable data regarding age was greatly underestimated at the beginning of our skeletal investigation and this difficulty is responsible in larger degree than any other single circumstance for the long period between the inception of the Western Reserve University collection of skeletons and the publication of studies thereupon. It is not everyone who knows his own age, and some of those who do make erroneous statements regarding their age for various reasons; and with dissecting room material there are probably still other sources of misinformation.

When we came to deal with the material collected here our early impression was one of discouragement so far as age was concerned. In the first place we paid too much attention to the skull, the state of obliteration of the sutures of which we used as a time marker. The sutures, both ectocranial and endocranial, merit special consideration, but up to the present we have found them less constant in their age relationship than certain other features of the skeleton. Secondly we relied too much on official Municipal records. Only after the hospital files were thoroughly organized and rendered worthy of serious attention did we realize that the data which we were gathering in the laboratory were far more trustworthy than official documents. Of late years there has been great improvement in records and this source of error can be largely discounted. A third factor which caused us to doubt seriously our results is the irregularity of the age curve. This is well shown in the polygon of ages of the material at present under investigation (Chart 1.) Whereas the polygon under thirty years and over sixty exhibits what one might expect to be the natural irregularity, the startling upward leaps of the polygon at thirty-five, forty, forty-five, fifty and sixty years cannot be explained in any such manner. No interpretation involving a fatal periodicity is acceptable and one can only say that individuals must be included who have given their ages in round numbers. We therefore set to work to exclude as discredited all skeletons of these ages which did

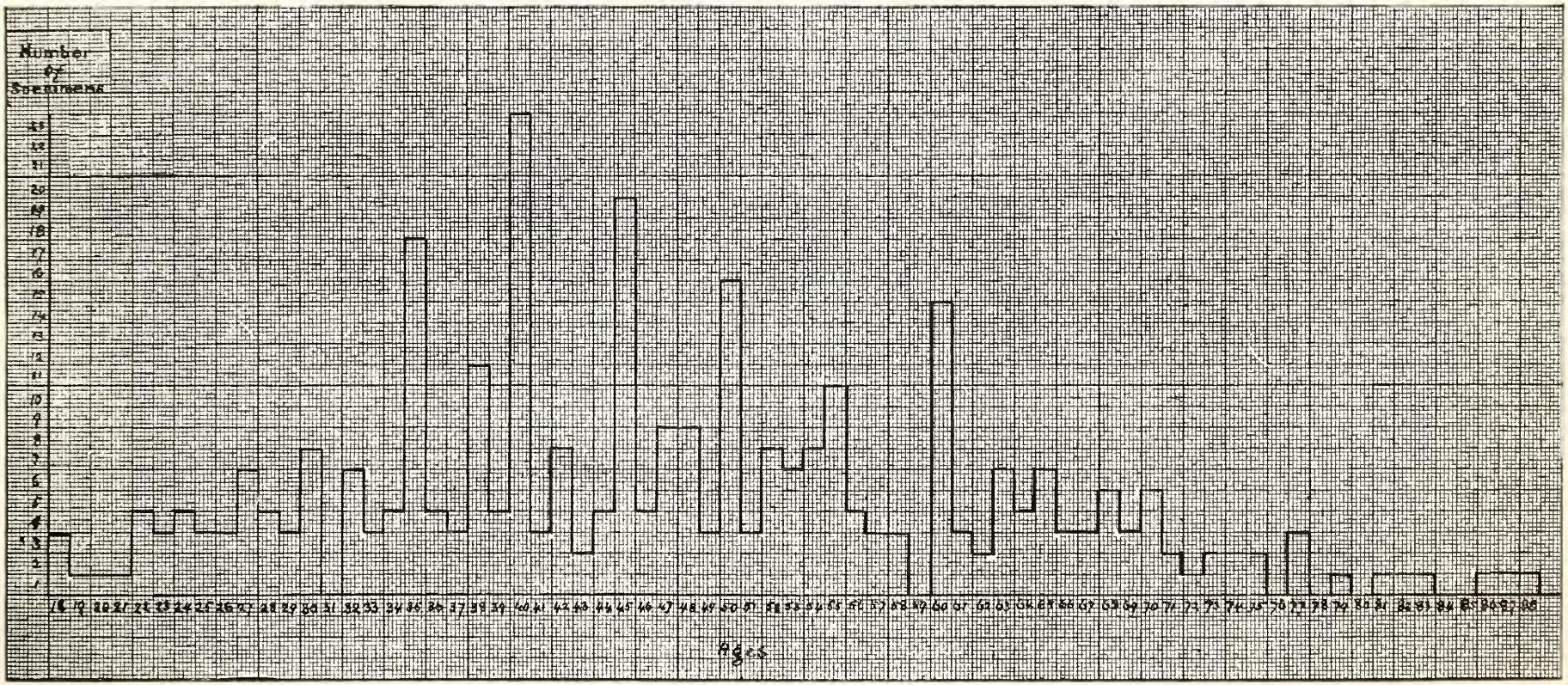


CHART 1. Polygon of age frequency—Male white pelves of known age.

Note the remarkably large number of skeletons of ages 35, 40, 45, 50 and 60 years and the considerable number at 38 and 55 years compared with the relatively uniform number at all other ages. This is probably explained by a tendency of individuals to give their age in round numbers.

not show a fairly constant relation to the age characters which we came to adopt as standards. We then found that skeletons of other stated ages gave us just as much trouble, and further we observed that certain diseases and defects have a marked influence upon skeletal features. Microcephaly, various forms of insanity, syphilis and to a less extent tuberculosis, considerably increase the apparent age of the skeleton. Hypophysial tumors, disorders allied to achondroplasia, and rickets retard the skeletal age. These are but a few examples. So that once more we were led to doubt the reliability of our data. Working over the material afresh we found that there are two types of age change, and that our dilemma had been caused by the confusion of the two together. One may be regarded as the normal developmental progress of the skeleton, the other as that induced by external factors such as disease, habits and use. In this study of the pubis, for example, we shall find that there are certain phases of metamorphosis which the bone normally undergoes and that these phases may be passed through with regularity, but we shall also see that progress may be accelerated, retarded or possibly even inhibited at any stage. Then there are other phases which cannot be regarded as perfectly normal. They may be frankly pathological, some falling under the caption arthritis, but they also may lie upon the border-line between the normal and the pathological in the sense that they occur in every individual sooner or later. It was only when we had learned to differentiate between these types of age change that our confidence was restored.

As an example of our early difficulties, skeletons 107 and 708 may be cited (see Fig. 65). Both are of age thirty-two and both have hospital records. Nevertheless No. 107 was discarded at first because of lipping of joints and No. 708 because of changes in bone texture. Later investigation showed that both retained many characteristics of the stated age but these were obscured, except for careful search, by the features probably induced by disease (arthritis in No. 107, tuberculosis in No. 708). Consequently both were restored to the series of known age.

It must be remembered that in this work we had no standards to fall back upon. All so-called age changes hitherto utilized we found to be largely surmises based upon material inadequate in point of numbers and data to fulfil the purpose which it was made to serve.

Finally we realize the inadequacy of our own material so far as statistical survey is concerned, but we do hold that it is now large enough to form the nucleus upon which some real knowledge of age

changes may be founded. The conclusion to which we have come as regards records of age is, that in the present state of our knowledge it would be unwise to eliminate any of those skeletons whose ages are not called in question by gross and obvious contradictions in the bones. In spite of the expectation that eventually we shall sift out some of our material of supposed known age, we feel strongly that at present we must adopt the course of accepting the stated age. To decline to do this before our knowledge is much more perfect than it is at present is to invite the disaster which is bound to follow the retention of preconceived ideas. Until we can prove beyond shadow of a doubt that misstatements have been made regarding age, it is safer to accept the records, controlled as they are in various ways elsewhere enumerated. We can at least feel sure that subject to the limitations common to all humanity our age records are dependable.

Gross Changes in the Pubic Bone

I. HISTORICAL

That gross changes are undergone by the pubic bone during the life of an individual is by no means a new idea. Cleland in 1889 wrote as follows (1): "The distance between the lines marking the inner limit of attachment of the femoral muscles on the right and left sides is considerably greater in the female than in the male. In a middle-aged or old female the line in question will always be seen marked by a distinct ridge, with a flattened surface extending inwards from it, covered in the recent state by the superficial ligament of the symphysis; and the distance between the two ridges of opposite sides will be found to increase as the pubic arch is approached." This distinction, Cleland says, has great constancy and is to be depended on, *provided ossification is thoroughly completed* [italics T.W.T.]. "The weak point of the character is that it is difficult to apply in the young adult. . . . The os innominatum is complete at both of these places [iliac and ischial epiphyses] considerably earlier than at the symphysis." Irregular ossific nodules upon the symphysial face of the pubis may be found distinct after the bone is everywhere else complete. "Probably ossification at this part is completed earlier in the male than in the female." Cleland obviously had a bias toward believing that the features, which I shall show to be age characters, are more distinctive of the female than the male and hence sex indicators. "Doubtless, also," he continues, "the body of the pubic bone continues to grow more rapidly towards the perineal border of the symphysis than at the abdominal border."

Following up statements by Litzmann and Matthews Duncan regarding changes in form of the pelvic brim, Cleland observes that until puberty both iliac and pubic parts of the brim can be lengthened by additions at their acetabular extremities, but that after the sutures of the acetabulum are obliterated, "the iliac part of the brim is incapable of elongation, while growth at the symphysis continues. . . till adult life." Apparently Cleland was unacquainted with the considerable amount of work already done upon the symphysial face of the pubic bone, the changes in which, as I shall endeavor later to show, are bound up causally with the increased distance between the "limiting lines of the femoral muscles of right and left sides." He also gives undue importance to the amount of actual growth of the pubic bone, that is to say elongation in the line of the *linea arcuata*, which can occur at the symphysial extremity after puberty.

Henle, in his Handbuch der Bänderlehre (1872), recognized that the symphysial face of the pubic bone undergoes variation in dimensions and texture with age and he describes in the following manner the form which he regards as normal, since "it is most frequently presented in middle age and is an intermediate form between extremes" "Die elliptischen Flächen, welche beide Hüftbeine einander zuwenden, haben hyalinische Knorpelbekleidung von ansehnlicher und über die ganze Oberfläche ziemlich bliebender Mächtigheit (2 bis 3Mm.). Sie sind im Frontalschnitt wellenförmig in Folge von Wülsten, welche mit grösserer oder geringerer Unterbrechung quer von hinten nach vorn über die Knochenfläche verlaufen und ohne Zweifel für die Festigkeit ihrer Verbindung mit dem Knorpel von Bedeutung sind. Zuweilen enthält der Knorpel isolirte Knochenkerne oder es finden sich Knorpelinseln, rings von Knochen umschlossen, der Oberfläche des letzteren (Aeby)."

Plainly Henle derived his information from Aeby's work as will shortly appear, although he did not clearly state the conclusions to which Aeby came.

The fact that the symphysial face of the pubic bone is not the same in texture throughout life, did not escape Waldeyer's artist, although these features are not stressed by the author himself. Fig. 18 in Waldeyer's Das Becken, which shows the left side of the pelvis, is clearly that of a young woman eighteen to twenty years old, for the typical rugged surface of the symphysial face is indicated although not very accurately drawn (3).

In most standard text books and figures the symphysial face of the

pubis is accepted as an oval surface, smooth in character and outlined by a perfectly regular margin. This however is the case only in pubic bones of the age of about forty years and upwards until secondary changes begin to make their appearance at fifty or over. These facts are passed over even by Martin in his Lehrbuch, where directions are given for measuring the height of the bony symphysis without any indication that this can be done with accuracy only in pelves which have reached the age of 35 or thereabouts (4).

Quite the most important contribution to the subject was made in 1858 by Aeby (5) who, like the many authors who had previously written upon the pubic bone, was interested primarily in the ligaments and soft tissues of the symphysis itself. Aeby describes the symphysial face of the pubis as a more or less irregular convex surface bounded by an oval outline, and of which the finer structural relations are largely lost in maceration. It is incorrect to assume, however, that the finer structural *features* are lost in maceration. The whole purpose of the present paper is to illustrate the constant change which these features undergo with increasing age. Apparently Aeby had no macerated material to work upon but was restricted to a comparatively small series of recent specimens which he studied by section. There is, of course no doubt that such a method permits most exact observations upon the fibro-cartilage in its relation to the bone and joint cavity, but for a complete study of the bony parts macerated material, the age of which is accurately known, is essential. The present paper therefore supplements and extends Aeby's observations as regards the bone. Aeby had sufficient material to enable him to see that marked changes are undergone by the bony symphysial face with age, for he states as a general law that with the passing of childhood the variety and irregularity of its form increase, but that later in life it once more becomes a single smooth surface. Aeby notes that, seen in coronal section, the outline of the surface in childhood forms a low, moderately smoothly rounded line, but that later it indicates a surface on which are horizontally directed furrows and ridges, which he concluded are of importance in establishing firm union with the cartilage. This new formation Aeby observes was noted by Tenon in 1806 and occurs in its most pronounced form after puberty, when the ridges have a height of 2mm. Later the corrugated appearance diminishes, but does not entirely disappear even in advanced age. This last clause does not accurately represent the condition in later life, as will shortly be shown, although the entire sentence is a brief but adequate statement of the actual facts.

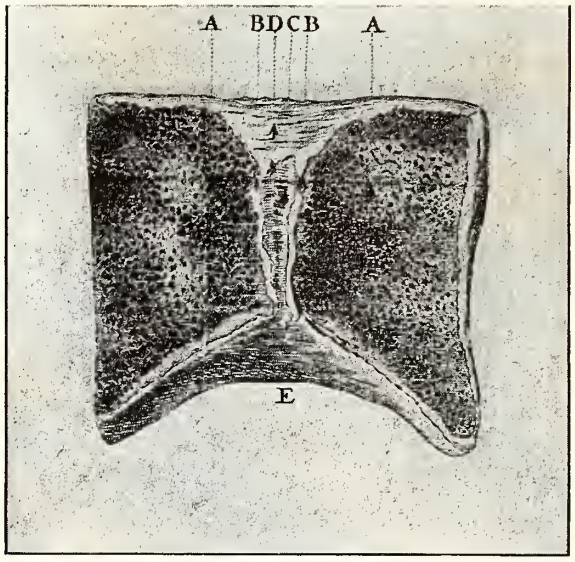
Aeby also observed age variation in the upper and lower extremities of the symphysial face, but he rightly commends the comparison of horizontal sections as showing most clearly the age changes. The outline in horizontal section, he notes, is often highly regular and even semi-circular in childhood but very soon becomes changed by the tendency to form angles [that is, borders], dorsal and ventral to the symphysial face. Of these the dorsal one forms first, and the ventral margin even elongates so that the symphysial surfaces of right and left sides are obliquely inclined toward each other to form an angle open ventrally. From this various successive gradations occur until eventually the surfaces are parallel, and moreover these gradations have a constant relation to age, although the author does not hazard what this relation actually is. But, Aeby goes on to point out, the growth of the bony margin is not symmetrical and only exceptionally do the two sides correspond. Here he was misled by the exagerrated impression of asymmetry which a study by cross-section alone is bound to give. In the figures accompanying this paper it will be seen that in the main the bony development is in reality fairly symmetrical. Similarly Aeby noted the presence of bony islands or cartilaginous islands especially along the ventral margin. We shall see that these are the natural result, in some cases, of the method of formation of the ventral margin. These features were already described in 1777 by Bonn (6). Further Aeby observed two of the asymmetrical formations which we shall have to discuss, namely, that in which both symphysial surfaces are curved towards the same side, and that where one symphysial face is markedly smaller than the other.

Aeby's discussion of purely sexual features we must defer until the female symphysis is considered, but we may now observe that he recognized the fact that at puberty the symphysial surface has practically reached its adult size. This is actually the case, but it must be remembered that Aeby was dealing with symphyses in the recent state and so measured the cartilage-covered surface. In our figures it is apparent that such measurements cannot be made upon the bone itself until the margins are definitely formed, that is to say until about the age of thirty to thirty-five years.

Aeby, being primarily interested in the soft parts was naturally eager to discover what occurs in these soft parts during pregnancy. He was strongly impressed with the vascular relations of the ligaments and indeed of the bones, had noted the occasional occurrence of inflammatory union of the two pubic bones described by Gurlt (7), though

Aeby himself had never seen such a case, and concluded that vascularity, or "periodic softening," is the cause of differences to be noted in the precise manner and speed of ossification between the sexes. This statement we shall discuss later but for the moment shall leave without comment.

To William Hunter belongs the credit of having observed the similarity between the symphysis pubis and the intercentral joints of the



IG. 1. A vertical section of the symphysis of the ossa pubis, in a female subject that had not been with child.

AA. The ossa pubis near the symphysis.

BB. The cartilaginous crust that covers and adheres to the surface of each bone at the symphysis.

C. The interior ligamentous substance, which connects the two gristles. It easily tears in the middle, upon bending such a preparation of the part as this; and, in dead bodies, it dissolves by putrefaction, much sooner than any other part of the joint.

D. The upper part of the symphysis, consisting of a strong ligament, which runs across from bone to bone.

E. A strong transverse ligament of the same kind at the lower part of the symphysis. (After William Hunter.)

vertebral column (13), a similarity which I find also in certain features of their bone change. Like Aeby and most others who have occupied themselves with the pubic symphysis, Hunter's attention was focussed upon changes in the soft tissues, but he certainly observed the lipping of the dorsal symphysial margin which occurs in later years, and there

is equally no doubt from his figures here reproduced (Figs. 1, 2) that he was acquainted with the ventral beveling which occurs during the third decennium.

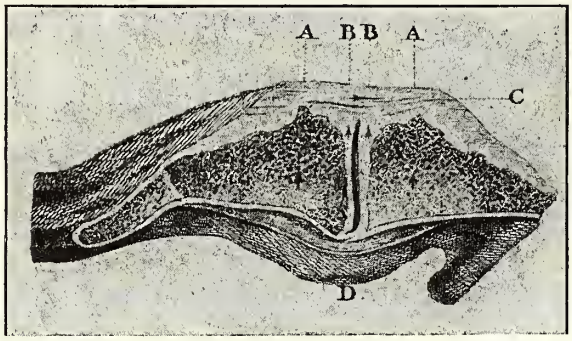


Fig. 2. An horizontal section of the symphysis of the ossa pubis in a subject who died of a fever in child-bed.

AA. The os pubis on each side of the symphysis.

BB. The cartilaginous crest that covers and adheres to the surface of each bone at the symphysis. The narrow dark space between these two cartilages represents the cavity of the joint, where the two cartilages played upon one another by loose surfaces when the ossa pubis were moved in different directions. These surfaces were not of a polished smoothness, as in most other joints; but a little unequal, as if they had been somewhat eroded. The ossa pubis were bound so firmly together that the surfaces of the two cartilages were kept close in contact; and upon drawing the bones from each other, when the section was made, they readily separated as far, and made such a cavity, as is represented in this figure.

C. The anterior transverse ligament of the joint which is blended with the tendious fibres from the adjacent muscles.

D. The internal transverse ligament of the joint. In some subjects it is very thick and strong; and then it makes a considerable projection all down the inside of the symphysis, as in this figure. (After William Hunter.)

Gross Changes in the Pubic Bone

II. TECHNICAL METHODS

As regards technique of preparation and presentation of the data in this paper there is little to explain. First, however, it is necessary to point out that in no case are the features presented either brought about or influenced by the technique of preparation. The symphysial face, upon which our attention is largely concentrated, is a modified diaphyso-epiphysial plane and, as such, may be expected to show a metamorphosis if not actual growth as an age feature. It is one of the objects of this paper to distinguish between metamorphosis and growth at this site.

Fig. 3. Ossa innominata of specimen 571, male, white, age sixty-nine.

Symphysial face shows some erosion and therefore falls into phase 10. Note the well marked lipping of the attachment of the sacro-tuberous ligaments.

The small rectangle shows the area represented in succeeding figures. The left os pubis is always to the left of the figure. The dorsal symphysial margins are remote from each other.

The article is profusely illustrated for the following reasons. First it is intended to serve as part of a guide in identifying approximate age of skeletons for those investigators who are held back from work in osteology by lack of precise information regarding the age of their material. Secondly, only by the study of many specimens can one appreciate fully the importance of the age changes discussed and the slight individual variations which occur. Thirdly whereas most anatomical laboratories have a fair number of skeletons of later adult age ready for study, in consequence of which it has been necessary in this communication to present merely a few typical such examples, young adult skeletons are rare and a considerable number of figures has been included so that the student may enlarge his acquaintance with this material which is not so easily obtained.

The photographs were all taken natural size and are reduced in reproduction by one-half. One must not infer however that any dimension measured upon the illustration and multiplied by two will give the exact measurement on the bone, for the specimens have been photographed from somewhat different angles in order to bring out better the special features to which attention is directed. The shadows also have been arranged with this object in mind. Although the photographs may not be used for precise determination of dimensions they do give an indication of the relative individual variation in size of the symphysial face. The orientation of the pubic bones can best be understood by reference to Fig. 3, which shows the two ossa innominata of specimen 571, a white male subject aged sixty-nine. The symphysial face of the pubic bones shows the secondary excavation which I shall describe as phase 10. But the purpose of this figure is really to indicate, by means of the small inset rectangle which includes the pubic symphysial area, what part of the bones is photographed in the illustration of this paper. It will be seen that the left pubis is on the left of each figure and the right bone on the right. Further, the ventral margins of the two bones are approximated whereas the dorsal margins are remote from each other. The bones are so arranged in order to bring the essential parts close together for photography and reproduction.

With regard to methods of pelvimetry, it has not been the intention at this stage to introduce tables of measurements and indices, but rather to deal with the morphological features first and in later communications discuss the measurements when these can be presented for both male and female, white and negro-hybrid together. Because of

their intimate relation to our studies, however, it has been necessary to employ certain measurements and the precise method employed is described each in its appropriate place. As I state later on in this paper, we have found the well-recognized measurement of pelvic height very unsatisfactory as a standard unit for the pelvis for reasons which I shall briefly outline. Naturally one would consider the matter very carefully before rejecting any anthropometric method with which so much work has been done as the total pelvic height. Full consideration of the matter would be beyond the scope of this paper but it will be necessary to explain shortly why I have chosen an altogether different standard for the symphysio-pelvic index.

Details of the measurement of symphysial height and of the height of the true (small) pelvis will be given in the appropriate section of a future paper. The methods followed by v.d. Broek (14, p. 12) could not be adopted. The lowest point of the tuber ischii, as he defines it, is not morphologically comparable on different human individuals or in Primates in general. Also the vertical measurement of the "rough surface" of the symphysial face is quite ambiguous especially in reference to age.

Gross Changes in the Pubic Bone

III. DESCRIPTIVE

In the series of 306 skeletons which forms the basis of this paper, it is to be noted that all are of the male sex and of White stock. Further we are concerned only with those changes which occur after puberty. We take therefore, as examples showing the condition of the pubic bone soon after puberty has been reached, skeletons 98 and 410 (Figs. 4, 5), both of stated age eighteen years, the age being confirmed by the characters of the entire skeleton in each case.

In both the epiphyses for the ischial tuberosities and for the iliac crests and anterior superior spines are merely commencing to unite with the main masses of bone. The epiphyses for the anterior inferior spines are already united on both sides in skeleton 98 and on the left side of 410. On the right side of 410 this epiphysis is incompletely united.

In both skeletons the symphysial face of the pubis presents a very striking appearance. It is traversed by ridges horizontally placed and separated by well marked grooves. In the upper part of the surface the ridges are more massive and traverse the entire breadth of the area; in the lower part they are smaller, are separated by shallower

grooves, do not pass across the entire surface and, on the contrary, tend to become confluent. In skeleton 98 the rugged symphysial face extends as far as and includes the pubic tubercle, but in No. 410 this is not the case for the pubic tubercle is already completely ossified, apparently without the aid of an epiphysis.

Epiphyses upon the symphysial face are erratic and very irregular. When they occur they form simply irregular bony masses or nodules fused with the upper or ventral part of the area. No such nodule occurs on the symphysial face of either of these skeletons.

Equally distinctive of the phase of growth represented by these skeletons is the complete absence of a delimiting margin to the symphysial face, which is nevertheless distinctly marked off from the ventral and dorsal aspects of the pubic bone by a sudden change in surface appearance and bony texture. A horizontal section through the pubis at right angles to the symphysial face would show a suddden termination of the deeply furrowed cartilage covered area at its ventral and dorsal limits. In similar though less abrupt fashion the symphysial area is delimited from the upper aspect of the pubic bone. The lower part of the surface, on the other hand, merges gradually into the smoother textured inferior pubic ramus. Thus we see that while the antero-posterior depth of the symphysial face may be measured with a fair degree of assurance, it is quite impossible to determine accurately the vertical diameter.

Skeleton 233 (Fig. 6) is of age 19 and in general illustrates the features just described for specimens 98 and 410, but is obviously slightly older, the bony features corresponding with the stated age. The iliac crests are uniting and the ischial epiphyses are united to the tubera though not to the rami. Examination of the symphysial face reveals no obvious change on the right side from the appearance noted in skeletons 98 and 410. On the left side of the pubis, however, there is slight indication of the formation of a ridge, which connects up the dorsal extremities of the horizontal furrows. This commencing delimiting dorsal margin becomes the most significant feature of the succeeding phase.

In brief then we may define the stage of ossification of the pubic bone in skeletons 98, 410 and 233 in the following manner:

First post-adolescent phase. Age 18–19. Symphysial surface rugged, traversed by horizontal ridges separated by well marked grooves; no ossific (epiphysial) nodules fusing with the surface; no definite delimiting margin; no definition of extremities.

We turn now to Figs. 7, 8, which represent the symphysial face of skeletons 583 and 248, and we note at once that the bone surface has lost to some extent the clear definition of its ridges, more so in No. 248 than in 583. This difference in appearance is distinct enough to indicate a step onward in the developmental process. No. 583 is of stated age twenty and No. 248 is of stated age twenty-one. In each case the condition of the skeleton confirms the age as given. In No. 583 the liiac crest epiphyses are almost united and show merely traces of the line of union. In No. 248 the iliac crests are entirely united and no vestige of the epiphysial line remains. In both specimens the the ischial epiphyses are still in process of uniting with the rami.

In accordance with this more advanced ossification of the os innominatum generally there are to be noted changes in the pubis. The ridge which was observed on the dorsal margin of the symphysial face of No. 233, linking up the hinder extremities of the horizontal ridges, is already better marked in No. 583 and is quite distinctly seen in No. 248. More especially in the latter the grooves adjacent to this dorsal delimiting ridge are filling up with a finely textured bone which is even encroaching upon the hinder extremities of the horizontal ridges. No. 248 in addition shows a bony nodule fused to the upper part of the face of the left bone, corresponding to the ossification center of an epiphysis. As will be seen later, this nodule, though exhibited by many examples, is not invariably present. When it occurs it helps to form the upper delimitation of the symphysial face, but this delimitation may occur equally well without the participation of the nodule in its formation.

Another feature begins to make its appearance during this period, although it cannot be said to be of much account until the succeeding stage is reached. This is a break-down of the ventral extremities of the ridges by rarefaction of the bony tissue affecting ridges and furrows alike and resulting in a distinct ventral bevel, seen very clearly in William Hunter's and Aeby's figures, and characteristic of post-adolescent stages. This will be appreciated better by noting the appearance of Figs. 7, 8, after observing the more pronounced condition shown in Figs. 9–16.

We may therefore summarize the appearance of the bone in these two specimens in the following manner:

Second post-adolescent phase—Age 20–21. Symphysial surface still rugged, traversed by horizontal ridges, the grooves between which are, however, becoming filled near the dorsal limit with a new formation

of finely textured bone. This formation begins to obscure the hinder extremities of the horizontal ridges. Ossific (epiphysial) nodules fusing with the upper symphysial face may occur; dorsal limiting margin begins to develop; no delimitation of extremities; foreshadowing of ventral bevel.

The next stage in development is mainly one of progressive rarefaction resulting in ventral beveling of the symphysial face, and is illustrated by Figs. 9–16. These represent Nos. 503 of stated age twenty-two, 471, 680, 694, all of stated age twenty-three, 628, 423, 688 of age twenty-four, and 584 of stated age twenty-five. As regards general ossification of the os innominatum, we note that in Nos. 503, 471, and 628 there is incomplete union of the ischial epiphyses to the rami, although union has progressed much further in the case of the last two than in No. 503. Nos. 608 and 694 show complete union of this epiphysis.

In all, the symphysial face clearly shows ridges and furrows the filling up and obliteration of the dorsal ends of which become progressively better marked, although there is no rapid change in this feature as there is in the succeeding phase. As already mentioned, the most characteristic appearance of the 22–24 year period is the beveling of the ventral border so striking shown in No. 694.

The ventral extremities of the horizontal ridges and grooves are obliterated by the appearance of a rounded and very porous vertical strip of bone gently beveling the symphysial face into the ventral surface of the pubic body. This takes the place of the abrupt differentiation between these two aspects noted in the foregoing examples. We shall see that from this stage onwards the porous beveled strip becomes more pronounced, until it is finally obliterated by the superposition upon it of the definitive ventral margin. The porous beveled strip is very well shown in section by Hunter's figure (Fig. 2).

In all specimens, except No. 688, there is a bony nodule fusing with the upper symphysial face. The dorsal margin gradually progresses in its definition, but there is no indication as yet of the extremities.

In Nos. 680 and 694 the less pronounced degree of ridge and furrow formation is worthy of more than passing notice, since it introduces us to one the variants upon the typical condition. Shortly it will become obvious that the degree of development of these varies considerably in different individuals, and further, that there is a distinct tendency to progressive obliteration of the ridge and furrow system with advancing age. In this connection Nos. 423 and 688 are very

important. The former is an example of the variant in which the ridge and furrow system has, seemingly, never been very well defined, while in No. 688 it is rapidly becoming obliterated.

Specimen 423, of definitely ascertained age twenty-four, illustrates for us a type of bone which at first caused some confusion until it was recognized that the only real difference lay in the fact that in it there is a greater general tendency to smoothness of the symphysial face. Accordingly the horizontal ridges and furrows upon this specimen are less pronounced, but the difference is one of degree only. The developing dorsal margin is present and the filling up of the hinder end of the furrows is also occurring, but these features are not so well-marked as in the more typical specimens, and at first sight seem to indicate that the growth processes have not progressed so far. The presence of a bony nodule at the upper end of each symphysial face however contraindicates this and there is no vestige of the line of union of the ischial epiphysis.

The beveling of the ventral margin is just as pronounced though not so obvious at first, as it is in the other specimens. Nos. 680 and 694 illustrate bones transitional in appearance between No. 423 and the typical form.

Nos. 688 and 584 show slight advances upon the other examples, for besides having a more clearly and completely defined dorsal margin they show the beginning of what one may call the dorsal plateau. In 688 the newly formed, finely textured bone adjacent to the dorsal margin has formed a narrow platform or plateau upon which the ridge and furrow system is obliterated. In this specimen the plateau is merely a narrow strip paralleling the dorsal margin.

In No. 584 the platform has increased throughout the length of the symphysial face and extends across one third of its breadth. In general, however, No. 584 is not developed so far as our other specimens of age twenty-five and hence it is included in the group of age twenty-two to twenty-four. We therefore summarize the foregoing features thus:

Third post-adolescent phase. Age 22–24. Symphysial face shows progressive obliteration of ridge and furrow system; commencing formation of the dorsal plateau; presence of fusing ossific (epiphysial) nodules; dorsal margin gradually becoming more defined; beveling as a result of ventral rarefaction becoming rapidly more pronounced; no delimitation of extremities.

Ages twenty-five and twenty-six see another important change

occurring in the pubic bone, namely the beginning of delimitation of the lower symphysial extremity. Figs. 17–20 illustrate the development of this phase. They represent pelves Nos. 575 of age twenty-five, 643, 424 and 490 of age twenty-six. The last mentioned introduces us to the succeeding phase in which delimitation of the upper extremity occurs.

In general one may say that this series, all of which except No. 424 show evidence of fusing bony nodules on the upper part of the symphysial face, exhibit a progression resulting in a remodelling of the symphysis. The horizontal ridges and furrows of an earlier age are absent or reduced to mere vestiges, and their place taken by a more or less uniform bony surface, much beveled and rarefied toward the ventral margin, and showing more or less of a denser-textured dorsal plateau immediately adjoining the dorsal limiting border. The dorsal plateau shows practically no increase in area beyond that of the preceding phase. It is the rapid advancement of the ventral porous beveled strip which has encroached upon and so largely eliminated the ridge and furrow system. Nevertheless it is during this phase, with the definite appearance of the dorsal plateau, that one may consider the dorsal limiting margin really completed.

The other feature which characterizes this phase is the development of the lower extremity. The beginning of definition is seen in No. 575. In the succeeding specimens the definition becomes progressively clearer.

The border line case No. 490, in addition to showing some indication of the upper extremity, also exhibits a small accessory nodule of bone about the mid-vertical point of the symphysial face towards the ventral aspect of the pubis. This is really a sporadic foreshadowing of the formation of the ventral rampart which will be described later.

Summarizing the changes just mentioned we can construct the following tabulation:

Fourth phase—Age 25–26. Great increase of ventral beveled area; corresponding diminution of ridge and furrow formation; complete definition of dorsal margin through the formation of the dorsal plateau; commencing delimitation of lower extremity.

Following rapidly upon the definition of the lower extremity is the delimitation of the upper extremity of the symphysial face, which forms the main feature of the next phase including skeletons from twenty-seven to thirty years of age. These are shown in Figs. 21–30, comprising Nos. 614, 341, 672 and 287, of age twenty-seven, 251,

and 215 of age twenty-eight, 288 and 712 of age twenty-nine, and 142, with 623 of age thirty. From now on it is to be observed that the regular sequence of age, hithereto noted, no longer holds so efficiently, partly because of natural individual variation, partly because of the increasing tendency in the late twenties and still more in the thirties for the bone to cease metamorphosing and retain an incompleted appearance. But this is a problem which will bear fuller investigation after we have studied the age-type specimens and we shall therefore pass on to describe briefly the characters of the series.

The symphysial face itself undergoes but little change. The dorsal plateau in most cases remains the same narrow platform that grew up about the age of twenty-five; in some it is broader than in others.

Sporadically, and very clearly in No. 142, the ridge and furrow system remains but is no longer a significant feature of the bone. In many but not in all there is present a bony nodule in the upper part of the surface. In No. 142 there is a possible retardation of metamorphosis, but having examined the entire skeleton we may be sure that retardation in general did not occur to any marked extent and if present it had not been of more than two or three years' duration.

The most significant change in this phase is the formation of the upper extremity. In some instances it is developed by the aid of a bony (epiphysial) nodule, but specimens 288, 712 and 142 (Figs. 27–29) show that it can be formed equally well without the intervention of the "epiphysis." We therefore summarize the phase in the following manner.

Fifth phase—Age 27–30. Little or no change in symphysial face and dorsal plateau except that sporadic and premature attempts at the formation of a ventral rampart occur; lower extremity, like the dorsal margin, is increasing in clearness of definition; commencing formation of upper extremity with or without the intervention of a bony (epiphysial) nodule.

The next stage in development of the pubis is very distinctly more difficult to appraise correctly than those which have gone before, but its essential feature is the completion or approximate completion of the oval outline of the symphysial face. The difficulties of interpretation result from several factors. In the first place there seems to be a greater individual variation than at younger ages; that is, the remainder of the developmental process may be hurried up or delayed more than the earlier phases. Secondly, the terminal phases

are more difficult to examine because they affect relatively minor details. Thirdly, there is a distinct tendency for the terminal phase to be cut short so that the typical adult form of symphysis is never attained. Fortunately at the age when examination of the symphysis uncontrolled by other observations on the pelvis begins to fail in its reliability, distinct age changes occur in other parts of the os innominatum, so that actually the age characters of the pubis never lose their value. Before taking up this further and more complex problem we shall study the features of the pubis between thirty and thirty-five years of age. These are illustrated by Figs. 31–44 which represent pelves nos. 238, 65, and 360 of stated age thirty; nos. 78 and 635 of age thirty two; nos. 671, 193 and 289 of age thirty three; nos. 342 and 301 of age thirty four; nos. 305, 104, 242 and 262 of age thirty five.

The two outstanding features of this series are the increasing definition of the extremities of the symphysial face and the formation of the ventral rampart.

As regards the former, it will be noted that the lower extremity varies in its distinctness and sharpness of outline according to the individual: in some specimens it is much more clearly defined than in others of the same age. Nevertheless it is certainly formed in all of the series.

The case of the upper extremity is somewhat different. Even if a bony "epiphysial" nodule entered into its formation little or no trace of the "epiphysis" now remains. The upper extremity is much more uncertain in its formation than the lower. It may be almost entirely absent, but in no instance have I found so little of it that I was unable to state precisely what was its definite limit. No longer is it impossible, as was the case in specimens of the decade below thirty years, to state with assurance the vertical diameter of the symphysial face.

The method of completion of the oval symphysial outline by the building up of the ventral margin is most interesting. Already in several earlier specimens a sporadic effort to commence this border by an outgrowth from the lower extremity has been observed. Also there have been indications of a downgrowth from the upper extremity, although this is less constant and more erratic in its behavior when it occurs. I have pointed out in the case of Nos. 215 and 341 that intermediate tubercles of bone occur between these outgrowths. In this series we may see for the first time the precise role which each of these three factors plays in completion of the oval outline. The ventral margin differs from the dorsal border and from the extremities

in that it is not simply a gradual addition of bone to a basis already present: it is entirely a new formation—a rampart built up on the obliquely beveled ventral rarefied or porous area of the symphysial face. Specimens 360 and 104 are the most instructive in showing the typical formation of this rampart, which is the result of linkage between the ventral prolongations of upper and lower extremities through new bone formation which may or may not be assisted by the presence of intermediate ossific nodules. In this process veritable bony bridges are formed and may be seen in many cases, a feature which attracted Aeby's attention. The development of the ventral rampart carries with it no formation of an adjoining plateau as does the dorsal margin, but the obliquely beveled ventral strip remains the same, and on both the symphysial and ventral aspects of the rampart the original rarefied bony surface remains. It is only in later phases that this "granular" appearance of the symphysial face and of the ventral aspect of the pubis becomes altered into a finer and more condensed bone.

It is not always, however, that the ventral rampart is formed in this typical manner. Oftentimes it gradually forms as in Nos. 238 and 78 by an obscure addition of bony tissue which is not sharply defined from the adjacent bone surface.

The ventral rampart is often incomplete. In Nos. 242 and 262 it has developed probably as completely as it ever would in these specimens. When a hiatus remains it is almost always in the upper third of the margin, as though the prolongation from the upper extremity had been too weak to complete its union with the upward growth from below.

Because of the variability in distinctness of the lower extremity and the uncertainty of completion of the ventral rampart, one cannot say that either of these features is more important as an age indicator. But by weighing together the amount of completion of the rampart and the definiteness of the extremities one may come to a fair estimate of the actual age, especially if these observations be checked up by the fact that in no case is there on the symphysial margins the lipping which is a distinct feature of older bones.

The summary of age changes just discussed is the following:

Sixth phase—Age 30–35. Increasing definition of extremities; development and practical completion of ventral rampart; retention of granular appearance of symphysial face and ventral aspect of pubis; absence of lipping of symphysial margin.

We pass now to a phase of development starting at about thirty-five years and continuing to an uncertain upper limit, which, for the sake of definition, may be stated as about thirty-nine. In this phase the paramount feature is a gradual change in the symphysial face and also the ventral aspect of the pubis from a granular texture to a more finely grained or dense bone, so that in many cases by thirty-eight years, and usually at forty, the symphysial face resembles the typical appearance figured in anatomical textbooks. As examples Figs. 45–51 are given representing the following: No. 181 of stated age thirty-seven (left only); nos. 321, 647, and 481 of age thirty-eight; no. 112 of age thirty nine; and no. 196 of age forty.

The variation in final condition of the ventral rampart in different individuals is well seen in this series. In all cases the extremities, especially the lower, are clearly defined and indeed the lower extremity is already forming with the dorsal and ventral margin part of a "rim" for the symphysial face. A little close observation of these figures enables one to realize when to discard the ventral rampart as an age indicator. It is incomplete on many of the bones and yet, from the changes going on in the symphysial face proper, it is clear that the rampart has reached its fullest degree of completion *for that individual.* This interpretation is confirmed by a study of the older bones to the consideration of which we shall shortly pass.

The changes in the symphysial face are quite obvious in the illustrations. The granular surface is giving place to a more finely textured bone on which may be seen, in some instances, remnants of the old ridge and furrow formation. But again as in the case of ventral rampart, this may not go on to completion. Nos. 112 and 196 are examples of aborted change, and that such interpretation is correct is evidenced by the fact that a further phase is already setting in, namely that of lipping of the symphysial borders. This lipping is not pathological, or at least it is not distinctly so. It is better defined as the ossification which occurs in tendinous and ligamentous attachments to bone after the age of thirty-five years. Full discussion of the problem of lipping must be deferred as beyond the range of the present paper, but it is necessary to dwell upon it shortly in its relation to age changes in the pubis.

I have already mentioned that, taken alone, the pubis is less reliable as an age indicator in the decennium beyond thirty years than it was for younger bones. Now appears this new feature of lipping to assist in the diagnosis.

Usually before there is the slightest lipping of the symphysial margins the attachment of the sacro-tuberous ligament begins to show an osteophytic growth which is sufficiently definite and constant in relation to age as to warrant use as an age indicator. This particular formation never occurs, in our experience, before the age of thirty-five years, and after that it progressively increases until certain dimensions and a well defined coarseness of structure are attained. The form which the lipping usually takes at the age of thirty-eight is shown in Fig. 46. This is specimen No. 647, the symphysial face of which is illustrated for comparison in Fig. 45.

It is at this stage also that there appears the marked differentiation between the ventral rampart and the pubis proper, through the outgrowth of bony tissue into the line of attachment of the gracilis muscle (Frazer, 12). This is the feature which struck Cleland's attention and was described by him as "the line marking the inner limit of attachment of the femoral muscles." Cleland's views have been referred to rather fully in the historical part of this paper and further discussion will be reserved until we consider in detail the view he expressed regarding growth of the pelvic brim in the symphysial area.

We may thus summarize the features of the pubis just given:

Seventh phase—Age 35–39. Changes in symphysial face and ventral aspect of pubis consequent upon diminishing activity; commencing bony outgrowth into attachments of tendons and ligaments, especially the gracilis tendon and sacro-tuberous ligament.

We have just seen that pelves 112 and 196 of ages thirty-nine and forty, respectively, show commencing lipping of the symphysial margins. This feature becomes of greater importance from now onward although it is still about five years before the lipping increases sufficiently to be generally of diagnostic importance. The bones of age greater than thirty-eight resolve themselves into three series, but much less accurately than those of the foregoing groups. Nevertheless we may state the approximate ages of the series next to be considered as thirty nine to forty-four. The main characteristic of this series is the general quiescence of the symphysial surface accompanied by a similar quiescence of the ventral aspect. This inactivity is indicated by a smoothness of texture specially evinced by the symphysial face. The rough, granular or pitted ventral aspect attains smoothness more slowly, but in typical bones of this period both surfaces are smooth and typical of text-book illustrations. A fair example of this phase is shown in Fig. 52, which is a photograph from specimen 314 of age

forty-two. There is a general smoothness of texture compared with previous figures. The oval outline is apparent if not very well defined, and the extremities are distinctly delimited. There is no pronounced lipping of the margins, the linear prominence appearing on the ventral aspect being in reality the line of attachment of the gracilis muscle, so greatly emphasized by Cleland as *the limit of attachment of the femoral muscles.* For a full statement of the number of specimens upon which this description and appreciation is based the reader is referred to the appendix. The features may however be summarized in the following manner:

Eighth phase—Age 39–44. Symphysial face generally smooth and inactive; ventral surface of pubis also inactive; oval outline complete or approximately complete; extremities clearly defined; no distinct "rim" to symphysial face; no marked lipping of either dorsal or ventral margin.

At approximately the age of forty-five, a new phase of the pubis appears, characterized by a well marked "rim" to the symphysial face, and in most instances by some lipping of both dorsal and ventral margins. Again, as in the last series, a full statement of numbers will be obtained from the appendix. As fairly typical examples we have chosen specimens 202, and 325 of ages fifty-two and fifty-three respectively (Figs. 53, 54). The photographs of these specimens are almost too good, for every irregularity in the surface is emphasized so that the general impression of relative smoothness of the surface is diminished. Indeed it is difficult in these as in many specimens to deny that there is indication of the succeeding phase 10. They show the outstanding features of the present phase 9 so well, however, that one could not fail to include them in an article in which it is desired to stress specially the salient points.

No. 202 shows the rim but no marked lipping. The rim is formed by the ventral rampart and by a similar narrow marginal projection developing upon the extremities and dorsal margin, comparable to but more distinct than the bony rim which develops round the glenoid fossa on the scapula.

In No. 325 the rim is not so distinct, but the lipping of the ventral margin is so pronounced that no lengthy description is required. It will suffice to observe that the lipping consists of an irregular, somewhat moniliform series of rounded projections developing upon the ventral aspect of the ventral rampart. The dorsal lipping is much more uniform and is practically an intensification of the edge of bone.

When either of these features is present in well marked degree the specimen may be allocated to this group with assurance. Many times, however, it is difficult to say whether a specimen should be classed in phase 8 or phase 9 because the lipping or the rim formation is so slight, but when in doubt concerning the phase one is justified in estimating the specimen at approximately the border line age, which in the case of the present series would be about forty-five.

The features of this series are, briefly the following:

Ninth phase—Age 45–50. Symphysial face presents a more or less marked rim; dorsal margin uniformly lipped; ventral margin irregularly lipped.

Commencing as early in occasional cases as age forty-eight but in general approximately at fifty, further changes occur in the pubis, the result possibly of pathological conditions. One has doubts about speaking of the features themselves as pathological although in some instances they probably are. The condition is one of rarefaction of the symphysial face accompanied usually by irregular ossification, so that very bizarre types of symphysis are ultimately developed. The process starts in one of two ways. Rarefaction takes place first either in the symphysial face itself, or along the ventral margin, in which case it usually begins in the upper third, especially if the ventral margin has never been fully completed.

Fig. 55 is a photograph of specimen 382 (age 50) showing rarefaction of the entire symphysial face, but this is quite early and the rim of phase 9 can easily be seen at the lower extremity of the left bone. The upper third of the ventral margin is very markedly eroded and from this the advancing rarefaction can be seen encroaching on the symphysial face.

Pelvis No. 547 of age fifty-three, illustrated in Fig. 56, stands in contrast with the last and represents the other type of bone. Here, although there is destruction of the ventral margin to some extent, the major erosion is in the symphysial face itself. In neither this nor the former case has phase 9 shown any very marked lipping of the ventral margin.

From these specimens one passes to consider more pronounced types. Fig. 57 from specimen 253 of age 58 is a well marked case of erosion deeply excavating the symphysial face and bringing about entire collapse of the ventral margin. Even in the midst of this wreckage of the symphysis, however, a remnant of the rim of phase 9 still persists in the dorsal margin and extremities. This is not so in No. 359 of age

sixty-three and represented in Fig. 58. Here the entire area is completely transformed into an irregularly pitted surface.

It is to be noted that from fifty years onward these secondary changes resulting in breaking down of the symphysial face increase in amount, and affect a greater proportion of individuals, until, as shown in the appendix, after the age sixty they are very frequent, and beyond seventy almost constant.

This is not the place to discuss the possible pathological nature of the secondary changes. The writer hopes at a later date to take up fully the senile features of the pelvis and this question properly belongs to that discussion. One can say, however, that they always commence in one of two ways, that they bear a more or less definite relation to age, that they are not associated with any definite disease of the bones which gives recognizable symptoms, and that the features of clinical lesions of the symphysis differ quite markedly from these.

The distinguishing characteristics of this period may be expressed thus:

Tenth phase—Age 50 and upward. Symphysial face eroded and showing erratic ossification; ventral border more or less broken down; disfigurement increases with age.

It will be observed from the foregoing description that the pubic bone is a much more reliable age indicator from twenty years to forty than after the latter age. Nevertheless taken in conjunction with other pelvic features it is an important time marker even in later life. One may tabulate the chief periods as regards the pubic bone very shortly and simply and the table will permit a close approximation to the actual age when taken in conjunction with other features of the pelvis. A short statement of the pubic age changes was published in my preliminary abstract in the Anatomical Record (8). This may now be amplified and amended for male white skeletons as follows:

Phase 1.—Age 18–19. Typical adolescent ridge and furrow formation with no sign of margins and no ventral beveling.

Phase 2.—Age 20–21. Foreshadowing of ventral beveling with slight indication of dorsal margin.

Phase 3.—Age 22–24. Progressive obliteration of ridge and furrow system with increasing definition of dorsal margin and commencement of ventral rarefaction (beveling).

Phase 4.—Age 25–26. Completion of definite dorsal margin, rapid increase of ventral rarefaction and commencing delimitation of lower extremity.

Phase 5.—Age 27–30. Commencing formation of upper extremity with increasing definition of lower extremity and possibly sporadic attempts at formation of ventral rampart.

Phase 6.—Age 30–35. Development and practical completion of ventral rampart with increasing definition of extremities.

Phase 7.—Age 35–39. Changes in symphysial face and ventral aspect of pubis consequent upon diminishing activity, accompanied by bony outgrowths into pelvic attachments of tendons and ligaments.

Phase 8.—Age 39–44. Smoothness and inactivity of symphysial face and ventral aspect of pubis. Oval outline and extremities clearly defined but no "rim" formation or lipping.

Phase 9.—Age 45–50. Development of "rim" on symphysial face with lipping of dorsal and ventral margins.

Phase 10.—Age 50 and upwards. Erosion of and erratic, possibly pathological osteophytic growth on symphysial face with breaking down of ventral margin.

The accuracy with which one may estimate age by means of the pubis was brought out very clearly in many of the specimens upon which this work is based, although no claim is made that there is any justification for using the pubis alone as an age indicator in case the entire skeleton is available for study. In the introduction it was mentioned that our files are completed by reference to City Hall records and Hospital case books. Our technique in the skeletal investigation is the following: After a survey of the entire skeleton the age is estimated by the investigator. Then the estimated age of the cadaver when first brought into the Department is produced. These two estimates are checked up with each other and with the City file. Lastly reference is made to the Hospital case book. The entire proceeding takes only a few minutes as all the records are at hand in the laboratory. We have observed, first as regards those bodies received during the few months after a political reorganization of the municipal Administration when the City Hall files were, in consequence, less accurately kept, and secondly in the case of those bodies received during the great influenza epidemic of 1918, when, by reason of the chaos inevitably resulting the City files were again less reliable, that the laboratory estimate was often at variance by several years with the City Hall statements. Practically always, in such cases, our experience has been that the Hospital case sheets have confirmed the laboratory estimate of age within two or three years up to 40 and to within five years beyond this age. In these laboratory estimates the pubic bone played an important but not the only part.

So far we have considered only specimens exemplifying what may be termed the typical progress in development of the pubis both as regards time and manner. One would not expect all pelves to fall into line with this classification. Hence we now turn to the consideration of pubic bones which show some apparent or real departure from the regular order; but upon the factors at work in controlling development of the os pubis very little light can as yet be shed.

Usually the outline of the symphysial face is an elongated oval, but, as discussed in another section of this memoir, the index of the surface varies because of increase in breadth in the decennia following completion of the ventral rampart. There is a rare type of symphysis, however, in which the vertical height is very small. This occurs once only in the present series, namely in No. 94 (Fig. 59). The height of the symphysial face of this individual is 22 mm. and his age twenty eight. Actually the specimen is at phase 8, but according to age it should be phase 5. There has therefore been in No. 94 some speeding up of the development of the symphysis which is at least correlated with the anomaly in form. From the photograph one can see very clearly the size which the symphysial face should have attained to be normal.

The next group of anomalous cases to be studied is represented by Figs. 61–66 inclusive. These are examples of mixed phases, the development of the pubis having advanced more rapidly and also more irregularly than is usually the case. In all these specimens the general skeletal age is somewhat greater than the stated age. In the first three (Nos. 649-age twenty-two, 667-age twenty-four, 267-age twenty-five), there are sufficient indications to prevent the experienced observer from classifying them in too high a phase. In the first place none shows lipping of the ligamentus attachments to the tuber ischii. In Nos. 649 and 667 the commencing formation of the extremities and even changes in the surface should not obscure the observation that the dorsal margin is as yet just forming. These examples then combine features of phases 3 and 5.

No. 267 of age twenty-five in like manner shows a mixture of phases 4 and 6. The dorsal margin is only just completed, and the dorsal plateau has not yet attained any appreciable breadth. The views of this specimen given in Figs. 62, 63 show very well the amount of bony tissue added to the symphysial face by the development of the ventral rampart and extremities after the ventral beveling has been completed.

Fig. 65, representing the symphysial face of No. 708, shows a rather anomalous phase 7. This individual died at age thirty-two with tubercular left hip, after old Pott's disease of the spine. All his bones show the texture and many characteristics of a man of fifty, yet I hesitate to invoke the inflammatory vascularity of the parts as causative. This vascularity and Aeby's inferences therefrom we can discuss to better advantage in a later contribution which will deal with the female pubis. No. 708 then shows changes in the symphysial face comparable with those usually noted between thirty-five and thirty-eight years of age.

The last example which we shall take of age changes in the pubis in advance of the actual years, is No. 68, illustrated in Fig. 66 and of age thirty-five. The features are those of phase 7, but they are obscured by the lipping of dorsal and ventral borders which we have seen to characterize phase 9. The man was a chronic alcoholic and eventually died of alcoholism. It may be that the exposure and irregularities connected with his habit are correlated with this lipping which is so unusual at this age.

We now glance at some of the cases showing retarded development of the pubis. For data as to the total number the reader is referred, as in the case of advanced specimens, to the classification of phases (pp. 328–9). A few illustrative types only are chosen.

No. 317 of age twenty-seven, Fig. 67, was a rachitic dwarf, who showed an extreme degree of kyphosis as well as other anomalies many of which certainly occurred as the result of retarded development. The dorsal margin is still in process of formation and the ventral beveling is still only poorly marked: hence the specimen falls into phase 3 and is retarded in development about four years.

No. 307 (Fig. 68) is a marked case of retardation. Though of age thirty-five the pubis shows features which cannot be classified as later than the border line between phases 5 and 6. There is nothing in the clinical record which seems to have bearing upon causation. In this specimen the pubis alone of all the skeleton is retarded in development.

No. 176 (Fig. 60), of age thirty-nine, on the contrary has clear indications of what brought about the retardation. This individual, whose pubis cannot be classified higher than phase 1, possessed in life a glabrous skin, eunuchoid features and infantile genitalia. The entire skeleton retained the condition usually attained at seventeen years, so far as epiphyses and other accepted indications of skeletal

age are concerned. A large osteoma was present in the sella turcica. So important is this specimen in its relation to bone development that a special study is being made of it. As regards the symphysial face, the surface shows no ridge and furrow system it is true, but we have seen that even in normal cases this becomes obscured and frequently entirely obliterated, that the obscuring process sets in at about twenty-five years, and that an entirely new texture of the symphysial face develops between thirty-five and thirty-eight years. Hence it is not astonishing that No. 176 has lost its ridge and furrow formation. The really important feature is the failure of any margin to develop. The consequent retention of phase 1 by this specimen, that is a phase in which there is still some slight actual growth at the symphysis, has resulted in a pubic-arcuate index of 61, which is greatly beyond that of other specimens of like phase.

Fig. 69 illustrates No. 185, of age forty, which is an important type and should be compared with Fig. 41 (No. 305) and later with Fig. 72 (No. 464). It is a specimen of delayed development and belongs to phase 7. The age suggested by the symphysis is thirty-five but the rest of the skeleton agrees quite well with the stated age forty. This is a genuine retardation without supervention of any of the changes which are characteristic of forty years.

The three specimens still to be considered illustrate mixed phases; but in these there is supervention of the phase more or less normal for the age upon a pubis of retarded development.

No. 210, of age forty-eight and illustrated in Fig. 70, shows the attempt of phase 8 to supervene upon phase 6. Obviously the ventral rampart in this bone has never developed and equally obviously there is a glossing over of the surface as formed, a kind of forced inactivity which has settled upon the bone and resulted in a somewhat wax-like appearance in place of the granular surface characteristic of phase 6.

No. 26 of age forty (Fig. 71), is from a skeleton the bone age of which, like the pubis in particular, indicates an age of about thirty-five years. But here as in No. 68 Fig. 66 there is a lipping more associated with phase 9. The supervention of phase 9 upon phase 6 in this case is also indicated by the formation of the symphysial "rim" so well seen on the left bone.

The last atypical example to which reference will be directed in this review is No. 464 (Fig. 72), of age sixty-five. In my first examination of pelves I classified this as phase 6, which indeed it is. But I failed at that time to recognize the very heavy lipping which is a feature of

the inferior pubic rami and other parts of the ossa innominata. I also failed to distinguish the secondary breakdown which is so well seen at the upper part of both symphysial faces, especially the left, and results in erosion of ventral rampart and symphysial face alike. The specimen is actually one of phase 10 supervening upon phase 6.

Before closing this section something should be said about frequency of retardations and advanced stages in relation to age, for it is the custom to reduce such observations to mathematical statements. In the present studies I maintain that such reductions are of little or no value. We have in this survey examined somewhat more than three hundred skeletons the majority of which are between thirty and sixty years of age. It is true that more than three hundred others have also been studied and must find their place in later communications. But admitting the entire series of between six and seven hundred, we have a very small number for any statistical study. Further the skeletons are random samples of very heterogeneous population, and thus the mathematical error stands to be very large.

One can state with assurance that types and phases here describe do occur and that their relation to age as shown by our material is approximately as I have tabulated it. Only by the addition of many more to this series and by constant checking, can one acquire sufficient data to make mathematical observations really worth while. To this paper is added an appendix giving the observations as regards phase and other relevant data. This appendix is intended to serve as the basis for further work, more especially upon this permanent material and by other workers who may desire to reinvestigate the views upon bone change here put forward. To this appendix I must for the present refer those who are interested in frequencies.

It does not appear advisable at this stage to discuss the asymmetrical forms of the symphysis, a subject touched upon by Aeby, for they can better be presented after we have considered the female, negroid and Primate material.

Nature of the Post-adolescent Bone Change in the Pubis

When John Hunter commenced his investigation upon the jaws and teeth, his attention was arrested by the fact that not only does the mandible grow in size but it is constantly remodelled to provide for the development and compensate for the loss of teeth (9). Extending his observations to the femur Hunter was confirmed in his conviction that bony change consists of two phenomena—increase (or

decrease) of substance and remodelling (10). In spite of the years which have elapsed since Hunter made this discovery Anatomists still fail to grasp the full significance of these axioms of bone change. During the past ten years Keith has emphasized anew the cardinal features of bone change (*e.g.* 11) and many of his theses find ample confirmation in studies under way in this laboratory.

With reference to the nature of the bony change at the pubic symphysial face I have been unable to find any direct statements except those by Cleland (1). Early in the paper Cleland speaks thus of unequal *growth* [*i.e.* increase of substance] at the symphysial face: "Doubtless, also, the body of the pubic bone continues to grow more rapidly towards the perineal border of the symphysis than at the abdominal border." Cleland formed the impression that the lower extremity of the symphysial face becomes defined before the upper, and in this we have seen that he was justified. But further on in the article the subject of age changes in the relationship of the conjugate and transverse diameters of the true pelvis is discussed. In reference to elongation of the pelvic brim, Cleland states that, "further, the sutures of the acetabulum become obliterated about puberty; and after that occurs the iliac part of the brim is incapable of elongation, while growth at the symphysis continues till adult life." I am not clear as to just when Cleland would consider adult age to be attained for he proceeds "the statement that the iliac and ischial epiphyses may not be completely united to the main bone till the twenty-fifth year is probably correct. But the os innominatum is complete at both these places considerably earlier than at the symphysis." It is evident from these and other parts of the paper that Cleland believed growth to occur in the sense of actual appreciable addition of bony substance at the symphysial face, sufficient indeed to cause alterations in the shape of the pelvic inlet after puberty. Aeby makes the statement that at fifty years the ossification process, if it has not reached its end has at least sunk to a minimum (5, p. 23). It seemed to me, in view of these statements, that we must ascertain precisely upon our material the nature of the bony change, for this can only be done on specimens the age of which is known. For this purpose I measured the ilio-pectineal line (linea arcuata) on both sides of each pelvis of all our male white specimens of known age from eighteen years to forty inclusive, comprising phases 1 to 8, subdivided the arc into its iliac and pubic components and expressed the pubic component as a percentage of the whole. In this investigation 113 pelves were used,

all being of known age. It will be noted that I measured the arc and not the chord. Cleland used the chord which is very misleading, as indeed he himself tacitly admits when he speaks of the considerable variety in the precise curve of the iliac component. The specimens of which only one os innominatum was available are included as they do not vitiate the results; they are marked by an asterisk. My technique is the following: The instrument used is a flexible steel measuring tape graduated in millimeters. The ilio-pectineal line is followed to the symphysial face and this termination is indicated by a pencil mark on the bone. The line is then followed backward to the auricular surface and the most forwardly projecting point of this articular area is also indicated by a pencil mark; this mark is not necessarily upon the ilio-pectineal line which often veers upward tangentially to the auricular surface. The ridge extending over the ilio-pectineal line from the prominence of the same name and marking the union of pubis and ilium is then traced in pencil. This ridge is often very slight and can usually be appreciated more exactly by touch than by sight. It is present upon all bones either as a ridge, which sometimes may be quite faint, or as a slight change in texture or color of the bone. The lengths of right and left ilio-pectineal lines and their pubic components are then averaged and expressed as the *pubic-arcuate index*, thus:

$$\frac{\text{Pubic component average} \times 100}{\text{Ilio-pectineal arc average}}.$$

According to Cleland the iliac and pubic chords are equal up to puberty, but after this the latter chord increases so that "in the European adult the pubic exceeds the iliac length from a quarter to three quarters of an inch." If the chord increases it follows that the arc must increase more.

Our results (Chart 2) in no way confirm Cleland's statement, unless his reference to adult age means twenty-one years and not the completion of the symphysial face. For practical purposes the bony change at the symphysial face after eighteen years of age represents a metamorphosis and not a growth.

In the polygon of phases the specimens are arranged in sequence of the pubic-arcuate index and not by sequence in the phase it elf. Absolute precision in the order of specimens in development is a difficult task and in the end unprofitable. In all phases except the first and second the range of index is practically the same, more than

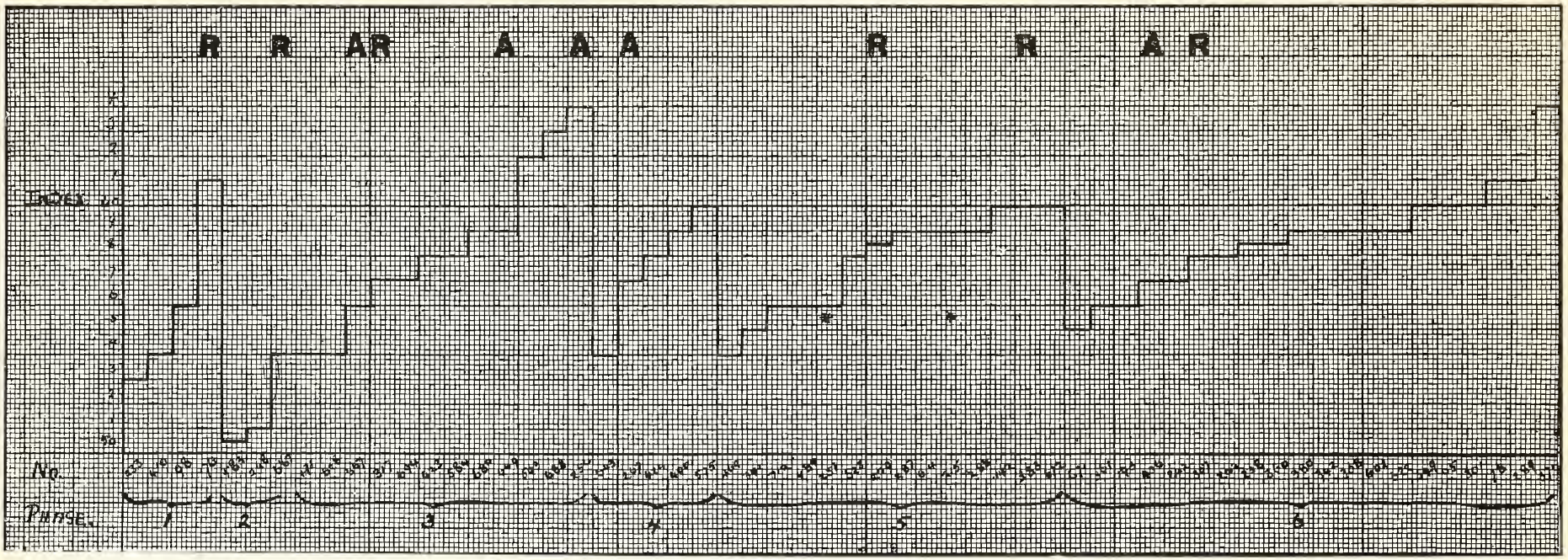


Chart 2. Polygon of pubic-arcuate index. Male white pelves of known age.

The polygon is arranged by phases and includes only those specimens the ages of which range from 18 to 40 years.

Within each phase the specimens are arranged according to index so that the lowest and highest ranges are readily seen. It will be observed that the ranges are practically the same through the entire series which means that there is no growth (*i.e.*, increase of substance) in the pubic component after the age of 18 years.

A. Specimen showing some acceleration of metamorphosis.

R. Specimen showing some retardation of metamorphosis.

(Cont'd p. 322.)

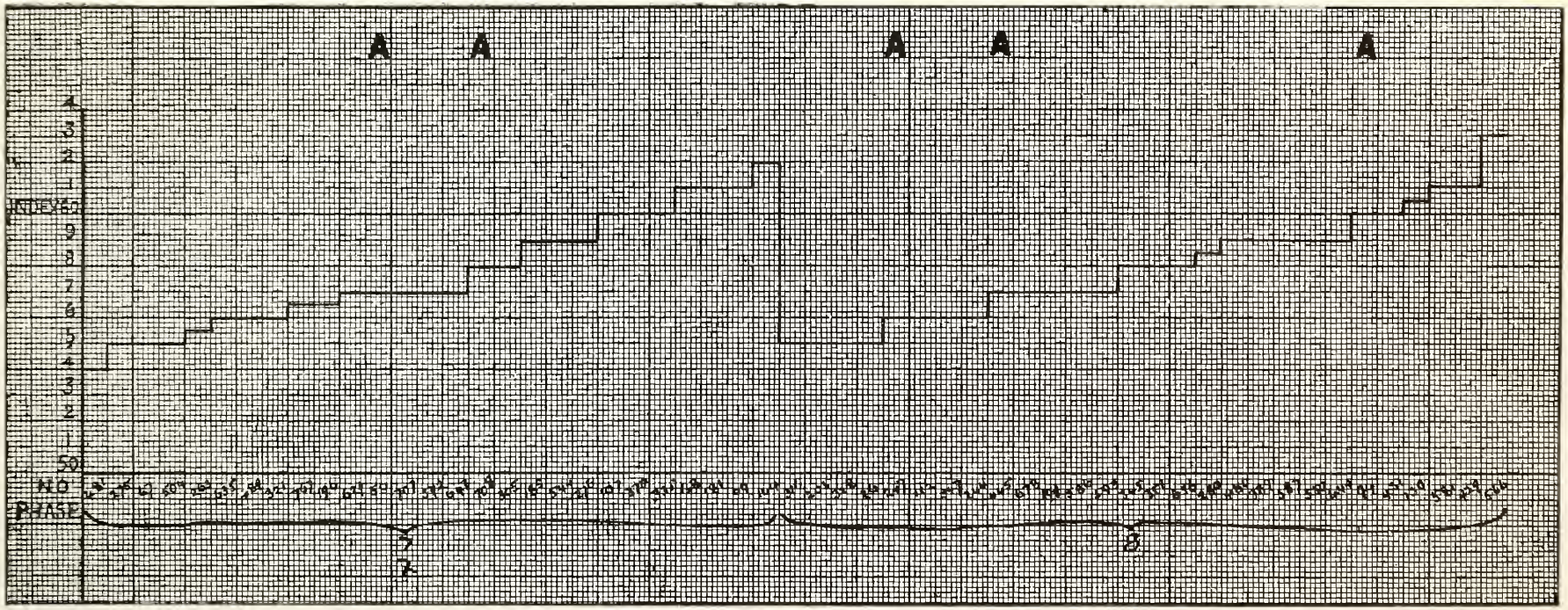


Chart 2a. Polygon of pubic-arcuate index. Male white pelves of known age.
A. Specimen showing some acceleration of metamorphosis.

three fourths of the pelves falling into the group with index of 55 to 60. If the limits 54 and 61 are taken as the normal extremities, then more than 90 per cent fall within the range.

It is true that the very young pelves of phases 1 and 2 have very low pubic-arcuate indices, and one must concede that probably some actual growth does occur between puberty and about twenty-one years. But after this age the polygon indicates simply individual variation, all phases having practically the same range.

It is important to note that those cases which I have regarded as anomalous, in that they are either advanced or retarded in phase for their age, do not lie at the extremes of the range. Neither hurrying up or slowing down of the bone change at the symphysial face has any appreciable effect upon the pubic-arcuate index except in No. 176 (Fig. 60), which is pathological in its retardation. Even this specimen however shows remarkably little addition of tissue in the symphysial face, considering the fact that at age thirty-nine its pelvis is still at about the seventeen-year stage.

To check this observation a polygon of the pubic-arcuate index was arranged in sequence of age. This polygon, including precisely the same pelves as Chart 2, showed precisely the same results. Apart from the slight increase of substance before the age of twenty-two years there is no evidence of actual growth. The maximum thickness of bone added to the symphysial face after the eighteenth year is probably fairly represented by the depth of the symphysial 'cap' in Fig. 63 (see pl. V). Owing to the ventral beveling, more bone is added by the ventral rampart to this margin and to the lower (perineal) extremity than to the other parts of the symphysial face. In this photograph of No. 267, age twenty-five, the distinction between the porous bone of the pubic body and the more compact ventral rampart can clearly be seen. The specimen was chosen for photograph because in view of its rapid development the distinction between these two masses of bone is strikingly evident.

There are two other dimensions besides thickness which must receive consideration, namely height and breadth of the symphysial face.

Aeby observed (5, p. 22) that at puberty the symphysis has pretty well reached its normal size, but he was dealing with fresh unmacerated pelves. We have seen from results previously set down in this paper that upon macerated material the symphysial height cannot be definitely stated until about the age of twenty-seven to thirty years, and

even up to thirty-five there may still be some doubt because until the extremities of the surface are defined its vertical diameter can only be estimated. In measuring the vertical height of the symphysis the following limiting points were used: above, the margin of the symphysial plateau which forms an abrupt edge with the upper surface of the pubis; below, the edge of the symphysis from which there falls away the ridge to which the subpubic ligament is attached. In cases where there is a definite *rim* to outline the symphysis I have taken the upper and lower extreme margins of the rim as my standard limits.

So far as absolute height is concerned our records tend to confirm Aeby's view that the pubic symphysis does not increase in height after adult age is reached. The individual variation in symphysial height is considerable, however, and to check the observations made on absolute height I resolved to form an index of the symphysial height based upon a stable unit. In these pelvic studies I had long before been compelled for two reasons to abandon the total pelvic height instituted by Turner and Garson as a basis. My first objection is that the total height is made up of two components, an iliac and an ischial; that these components are influenced by entirely different factors; and that iliac and ischial elements being set at varying angles in different Primates give a total height which is not comparable throughout the Primate series including Man. My second objection is that the total pelvic height cannot be measured, because the precise position of any landmarks differs from pelvis to pelvis so that the loose term "greatest height" gives merely the roughest comparison. The pubic symphysis however is part of the true pelvis and as such should be compared with the height of the true pelvis alone. Limits for the measurement of true pelvic height can be precisely defined and the measurement applies equally to Man and to other Primates. Above, the limiting point is the line of union of pubic and iliac bones where this cuts across the ilio-pectineal line (linea arcuata). The limit below is that point, upon a more or less clearly defined line separating the area of muscular attachment upon the tuber ischii from the area covered by fibrous tissue and bursa, which is furthest removed from the upper limiting point. This is found approximately in the center of the transverse diameter of the tuber. The symphysio-pelvic index is obtained thus:

$$\frac{\text{Average height of right and left symphysis} \times 100}{\text{Average of right and left true pelvic heights}}.$$

The upper limit can always be felt by the finger within one millimeter to iliac or pubic side, even though it is scarcely visible. Sometimes there is a slight ridge or even a bridge of bone forming a mound above the regular line of the linea arcuata. In case such a mound is present the measurement is taken below the mound in the direct line of the linea arcuata.

The lower point is not always quite clearly defined. This is especially true of young subjects, in whom however the symphysis is also not measurable. The point has no reference to the most outstanding part of the tuber which in some cases is most prominent below the limiting point, sometimes above it.

The symphysio-pelvic index, like the absolute height of the symphysis, gives no evidence so far of increase in symphysial height after adult age is reached.

In the last place the maximum antero-posterior diameter of the symphysial face has been investigated. The measurement of this is quite simple and the only tangible result is the one which would be expected from the description of phase 9, namely that during this period there is slight increase in symphysial breadth. The increase however is entirely due to the lipping which is characteristic of the phase.

The great mass of figures connected with these observations on symphysial height and breadth is not presented in this paper. In later studies upon the pelvis it may serve some useful purpose but at present it would only convey in cumbersome and obscure form what can be stated briefly and much more clearly in a few works. What I do feel is important is to record the method adopted and the reasons for its adoption.

It has been noted from the foregoing pages that from the eighteenth year onward the changes undergone by the pubic are largely if not entirely a metamorphosis and not an actual growth, at least in the neighborhood of the symphysial face. Cleland's observation upon the increased distance in older pelves between the "limiting lines of the femoral muscles of right and left sides" was based on a misconception of the pubis. It is the formation of the ventral rampart which causes the muscular attachment to recede from the edge of the pubis in the macerated bone, but this is no evidence that an increase in distance is to be met with in fresh or living subjects.

As regards Aeby's work, we recall that it was done upon fresh non-macerated material and by horizontal sections through the symphysis.

The observations made by Aeby are thoroughly confirmed by the work now presented, the only difference being that whereas Aeby's descriptions are all of sections through the symphysial face, ours refer to the features of the surface fully seen. How close are the resultant observations obtained by the two methods of attack can be clearly seen by comparison of the synopsis of the various phases as given above with the extracts of Aeby's work quoted earlier in the paper. Only in minor details do marked discrepancies occur.

Summary and Conclusions

A. SUMMARY

1. Distinct changes occur in the adult skeleton unrelated to childhood or senility. These are sufficiently closely related to age as to be valuable as time-markers.

2. Among the age changes are certain characteristic features of bone adjacent to certain joints, the bone surface resembling in part a diaphyso-epiphysial plane.

3. The pubic bone adjacent to the symphysis presents features of this kind.

4. The present paper deals with male white pelves of known age. It is to be followed by observations on female, negro-hybrid, and Primate pelves generally.

B. CONCLUSIONS RELATIVE TO THE MALE WHITE OS PUBIS

5. The ossification of the pubic tubercle is completed by the creeping of new bone over the rough diaphysial face of the tubercle and not necessarily by the union of a characteristically ossified epiphysis.

6. Ossified epiphyses for the symphysial face are rudimentary, erratic in their occurrence and very irregular in form. When they occur they rapidly fuse with the symphysial surface, usually in its upper area, taking part in the formation of the upper extremity and losing their identity very quickly.

7. The symphysial face undergoes a distinct metamorphosis after puberty. Of this the various phases are tabulated on p. 328. They have a definite but not an invariable age relationship.

8. In occasional cases this metamorphosis is not carried to completion as regards ventral margin and upper extremity.

9. Partial acceleration or retardation is exhibited in the metamorphosis of a few specimens (*e.g.*, No. 142). Had such individuals

lived a few more years the modification might have become more distinct.

10. Anomalies of the symphysis may affect the age relationship of its metamorphosis.

11. General diseases and habits of life also affect more or less profoundly the age relationship of the pubic bone change.

12. In most cases there is a practical harmony in the age relationships of various parts of the skeleton, but occasionally the stage of bone change in the os pubis finds itself at variance with the indications of other bones.

13. Investigation by various methods shows that there is little actual increase of bony substance at the symphysial end of the os pubis after the eighteenth year, and none at all after the twenty-first. In the main and practically entirely the symphysial change is one of metamorphosis.

APPENDIX

I. Classification of Pubic Bones: Male White Pelves for Known Age

Age	Phase	Subjects
18	1	98, 410 (wet specimen) 391
19	1	233
20	2	583
21	2	248
22	3	256 (admixture of phase 6), 503, 649 (admixture of phase 5)
		72 (wet specimen)
23	3	471, 480, 694
24	3	423, 628, 667 (admixture of phase 5), 688.
25	3	584
	4	267 (admixture of phase 6), 575.
26	4	424, 490, 643
27	3	317, 687
	5	287, 341, 614, 672
28	5	215, 251, 469
	8	94 (very anomalous)
29	5	288, 436 (admixture of phase 6), 712
30	5	142, 484, 623
	6	65, 238, 360
	8	247
32	6	78, 549
	6–7	635
	7	107 (slightly pathological), 707, 708
33	6	193, 289, 671.
34	6	301, 342
	6–7	629
	7	489
35	5	383
	6	242, 262, 308, 361, 371, 602, 622
	6–7	104, 305, 592
	7	56, 68, 370, 544
	7–8	205, 280
36	5	209
	5–6	307
	7	767
	8–9	445
37	6–7	181
	7	263, 504
38	6	380
	7	275, 321, 481, 647
	7–8	345, 480
	8	328, 581, 678
	8–9	389
39	1	176 (Hypophysial tumor).
	8	112 (superposed on phase 6), 130
	8–9	550
40	7	67, 69, 185, 196, 276, 335, 459
	7–8	244
	8	199, 316, 347, 429 (upon phase 6), 431, 449, 566, 582 (upon phase 6), 587 (upon phase 6), 656
	8–9	351, 586
	9	26 (upon phase 6), 593 (upon phase 6), 740 (upon phase 7)
41	8	295, 375 (upon phase 6)
	8–9	650
42	8	227, 314, 640 (upon phase 6)
	8–9	494
	9	255, 365, 654 (upon phase 7)
43	6–7	661
	8–9	189
44	9	194, 605 (upon phase 7), 608
	10	348 (upon phase 8)
45	8	374, 395, 518 (upon phase 6)
	8–9	73, 80, 156, 313, 320, 336, 444
	9	268, 274 (upon phase 7), 282, 369, 460 (upon phase 7), 689, 787
	10	285, 467
46	9	155, 186 (upon phase 6), 364
47	8	214
	8–9	39, 41, 318
	9	36, 669 (upon phase 6), 701, 711
48	8	210 (commencing; upon phase 6)
	9	213, 322, 390, 559 (upon phase 7)
	9–10	296, 354
	10	745
49	9	208
	10	344 (pathological), 507
50	9	218, 261, 265 (upon phase 7), 266, 398, 432, 535, 648, 732
	9–10	183 (?pathological), 200, 382, 492
	10	50 (upon phase 8), 195
51	8	468
	9–10	264, 377
52	8	18 (pathological?)
	8–9	292

Age	Phase	Subjects	Age	Phase	Subjects
52	9	23 (upon phase 7), 202, 562	65	10	464 (upon phase 6), 579, 686 (upon phase 8), 691
	9–10	372			
	10	496	66	9–10	207, 358
53	9	28, 197, 325, 609		10	309
	10	547, 641	67	9–10	329
54	9	418, 463 (upon phase 6), 789		10	76 (strongly resembles phase 6), 483 (upon phase 6)
	9–10	48, 322, 610, 726			
55	9	597	68	9–10	35, 353
	9–10	270, 303, 499, 537, 615, 621, 746		10	186, 286, 573
			69	9	277
	10	300 (upon phase 6), 477		10	271, 571
56	9	258	70	9	284
	9–10	452		9–10	304
	10	393, 554		10	187 (upon phase 6), 191, 216 (upon phase 6)
57	9	797			
	9–10	212, 788	71	9	37
58	9	487		9–10	683
	9–10	479	72	10	179
	10	253	73	9–10	739
60	9	556, 636, 651		10	272
	9–10	21, 82, 217, 220, 250, 546, 551, 663	74	9	224, 323
			75	9	66
	10	396, 660, 780		9–10	236
61	9	219	77	9	283
	9–10	239		9–10	92
	10	294		10	114
62	9–10	231	79	9–10	77
	10	567 (pathological)	81	10	397
63	9	319, 349	82	10	381 (pathological)
	9–10	206	83	10	616
	10	312, 359, 557	86	10	235
64	9–10	71, 75, 363, 665	87	10	51
65	9	299, 426	88	10	115

In the foregoing statement several comments are made. In case the specimen is distinctly pathological the fact is recorded. A mingling of two phases in any one specimen is duly noted. Where a later phase is mingled with the earlier typical one the mingling is stated as an admixture. These notes are not found on specimens of more than twenty-nine years, but where they occur they indicate a tendency to unusually rapid metamorphosis. In specimens of age thirty-nine and over markedly advanced metamorphosis is not so obvious nor so easily identified. Among these retardation is the striking feature. The characteristic phase is recorded as supervening upon the earlier phase during which metamorphosis of the retarded specimen became inhibited or greatly slowed down. Naturally frank cases of acceleration or retardation are recorded by phase without comment. One immediately wonders if acceleration and retardation are characteristic

of early and late adult life respectively. The list of specimens answers this in the negative. Then one asks oneself if retarded specimens have their metamorphosis inhibited or simply slowed down. No satisfactory answer can be returned to this question upon the basis of the number of examples here recorded. The subject will be taken up after presentation of female and negro-hybrid pelves in a later communication.

II. Data for Pubic-arcuate Index

The figures for the estimate of this index will be presented along with those for the female and negro-hybrid pelves in later communications.

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Explanation of Plates

PLATE I.

The symphysial face of phases 1, 2 and 3 comprising ages 18 to 24 years.

Phase 1. Figs. 4, 5, 6.

Fig. 4. No. 98, age 18. Symphysial face rugged; traversed by horizontal ridges and furrows. Ridges are more massive above and transverse entire breadth of face. Below they are smaller, tend to be confluent and do not pass across the entire surface. No bony nodules on upper part of face which extends to pubic tubercle. No definite margins: no delimitation of extremities. Appearance of delimitation below on right side is due to photographic foreshortening.

Fig. 5. No. 410, age 18. Symphysial face no longer extends as far as pubic tubercle.

Fig. 6. No. 233, age 19. Definitive dorsal margin commencing on left side only as ridge which connects up the hinder extremities of the horizontal ridges.

Phase 2. Figs. 7, 8.

Fig. 7. No. 583, age 20. Dorsal delimiting margin is now present on both sides.

Fig. 8. No. 248, age 21. Adjacent to growing dorsal margin the horizontal furrows are filling with new, finely textured bone which is wrecking the hinder extremities of the ridges. Bony nodule fusing with upper left face. Illusion of delimited lower extremity is entirely due to photographic foreshortening.

Phase 3. Figs. 9–16 incl.

Fig. 9. No. 503, age 22.
Fig. 10. No. 471, age 23.
Fig. 11. No. 680, age 23.
Fig. 12. No. 694, age 23.
Fig. 13. No. 628, age 24.

In all these figures the dorsal margin remains about as it is in phase 2 but the surface pattern of ridges and furrows is being wrecked first by the growth of the dorsal plateau adjacent to the dorsal margin and secondly by the beveling of the ventral strip (compare Fig. 2). The bony nodule occurs on all. No delimitation of extremities.

Fig. 14. No. 423, age 24. An example of the shallow-furrowed type of symphysial face. Bony nodules present.

Fig. 15. No. 688, age 24. Dorsal plateau extends forwards over one third breadth of face. No bony nodules.

Fig. 16. No. 584, age 25. Contrast the distinctions of ridge and furrow system of this specimen with that of No. 688 although same stage is exhibited in both. Bony nodules present.

PLATE II.

The symphysial face of phases 4 and 5 comprising ages 25–30 years.

Phase 4. Figs. 17–20 incl.

Fig. 17. No. 575, age 25.
Fig. 18. No. 643, age 26.

Fig. 19. No. 424, age 26.
Fig. 20. No. 490, age 26.

All these specimens show continuance of wrecking of ridge and furrow system with obscuring of identity of bony nodules (except in No. 424 where they do not occur). Note the greatly increased ventral erosion and the commencing formation of the lower extremity.

Phase 5. Figs. 21–30 incl.

Fig. 21. No. 614, age 27.
Fig. 22. No. 341, age 27.
Fig. 23. No. 672, age 27.
Fig. 24. No. 287, age 27.
Fig. 25. No. 251, age 28.
Fig. 26. No. 215, age 28 (left only).
Fig. 27. No. 712, age 29.
Fig. 28. No. 288, age 29.
Fig. 29. No. 142, age 30.
Fig. 30. No. 623, age 30.

The symphysial face has undergone little change from phase 4, but the lower extremity becomes better marked and sporadic attempts occur at formation of ventral rampart. In some the bony nodules have developed and are losing their identity. No. 142 retains the ridge and furrow system to a marked extent. The upper extremity is beginning to form on all with or without the aid of a bony nodule.

PLATE III

The symphysial face of phase 6 comprising ages 30–35.

Phase 6. Figs. 31–44 incl.

Fig. 31. No 238, age 30.
Fig. 32. No. 65, age 30.
Fig. 33. No. 360, age 30.
Fig. 34. No. 78, age 32.
Fig. 35. No. 635, age 32.
Fig. 36. No. 671, age 33.
Fig. 37. No. 193, age 33.
Fig. 38. No. 289, age 33.
Fig. 39. No. 342, age 34.
Fig. 40. No. 301, age 34.
Fig. 41. No. 305, age 35.
Fig. 42. No. 104, age 35.
Fig. 43. No. 242, age 35.
Fig. 44. No. 262, age 35.

The outstanding features of this phase are the increasing definition of the extremities and the formation of the ventral margin. Often but not always the latter is formed by the building up of an actual rampart by extensions from upper and lower extremities, including also, it may be, occasional bony nodules between. In some cases the ventral margin seems to form in the same manner as the dorsal margin (see No. 78). The symphysial face undergoes little change in this phase.

PLATE IV

The symphysial face in phases 7, 8, 9, 10 comprising ages 35 years and upwards.

Phase 7. Figs. 45–51 incl.

Fig. 45. No. 647, age 38.
Fig. 46. No. 647, medial margin tuber ischii.
Fig. 47. No. 181, age 37.
Fig. 48. No. 321, age 38.
Fig. 49. No. 481, age 38.
Fig. 50. No. 112, age 39.
Fig. 51. No. 196, age 40.

These bones all show changes in the symphysial face (and ventral surface) consequent upon diminishing bone activity.

Fig. 46 shows the lipping which occurs during this phase at the attachment of the sacro-tuberous ligament.

Phase 8. Fig. 52.

Fig. 52. No. 314, age 42.

Note relatively smooth and generally inactive symphysial face with complete oval outline, clearly defined extremities, no "rim" or marked lipping of margins.

Phase 9. Figs. 53, 54.

Fig. 53. No. 202, age 52. Show the development of a distinct narrow border or "rim" to the margin.

Fig. 54. No. 325, age 53. Shows uniform dorsal lipping and irregular ventral lipping.

Either or both of these features are present in phase 9.

Phase 10. Figs. 55–58.

Fig. 55. No. 382, age 50. Shows erosion of upper third of ventral margin.

Fig. 56. No. 547, age 53. Shows erosion primarily of symphysial face and secondarily of ventral margin.

Fig. 57. No. 253, age 58. Marked erosion of surface and break-down of ventral margin.

Fig. 58. No. 359, age 63. Complete senile transformation of symphysial face.

PLATE V

Examples of anomalies in age-relationship of change in os pubis.

Fig. 59. No. 94 age 28. Acceleration of development related to anomaly in form.

Fig. 60. No. 176, age 39. Very marked retardation of pubic development associated with osteoma in sella turcica.

Fig. 61. No. 649, age 22.
Fig. 62. No. 267, age 25.
Fig. 63. No. 267, ventral surface of ossa pubis.
Fig. 64. No. 667, age 24.
Fig. 65. No. 708, age 32.
Fig. 66. No. 68, age 35.

All these specimens show acceleration of pubic metamorphosis. For descriptions see text.

Fig 63 shows the ventral rampart of denser bone standing upon the more porous ventral beveled strip.

Fig. 67. No. 317, age 27.

Fig. 68. No. 307, age 35.

Fig. 69. No. 185, age 40.

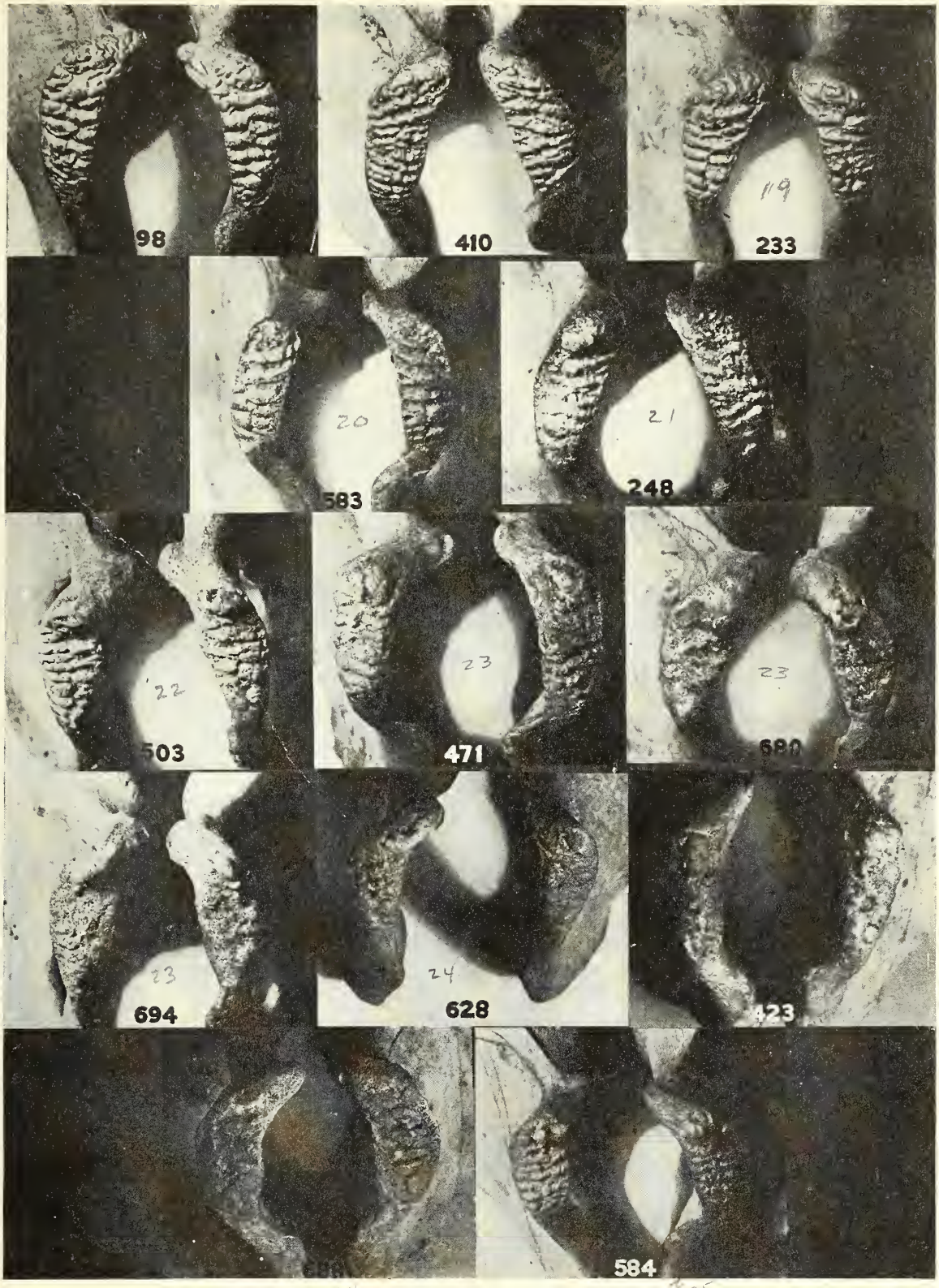
Fig. 70. No. 210, age 48.

Fig. 71. No. 26, age 40.

Fig. 72. No. 464, age 65.

All these figures show retardation of metamorphosis. For complete description see text.

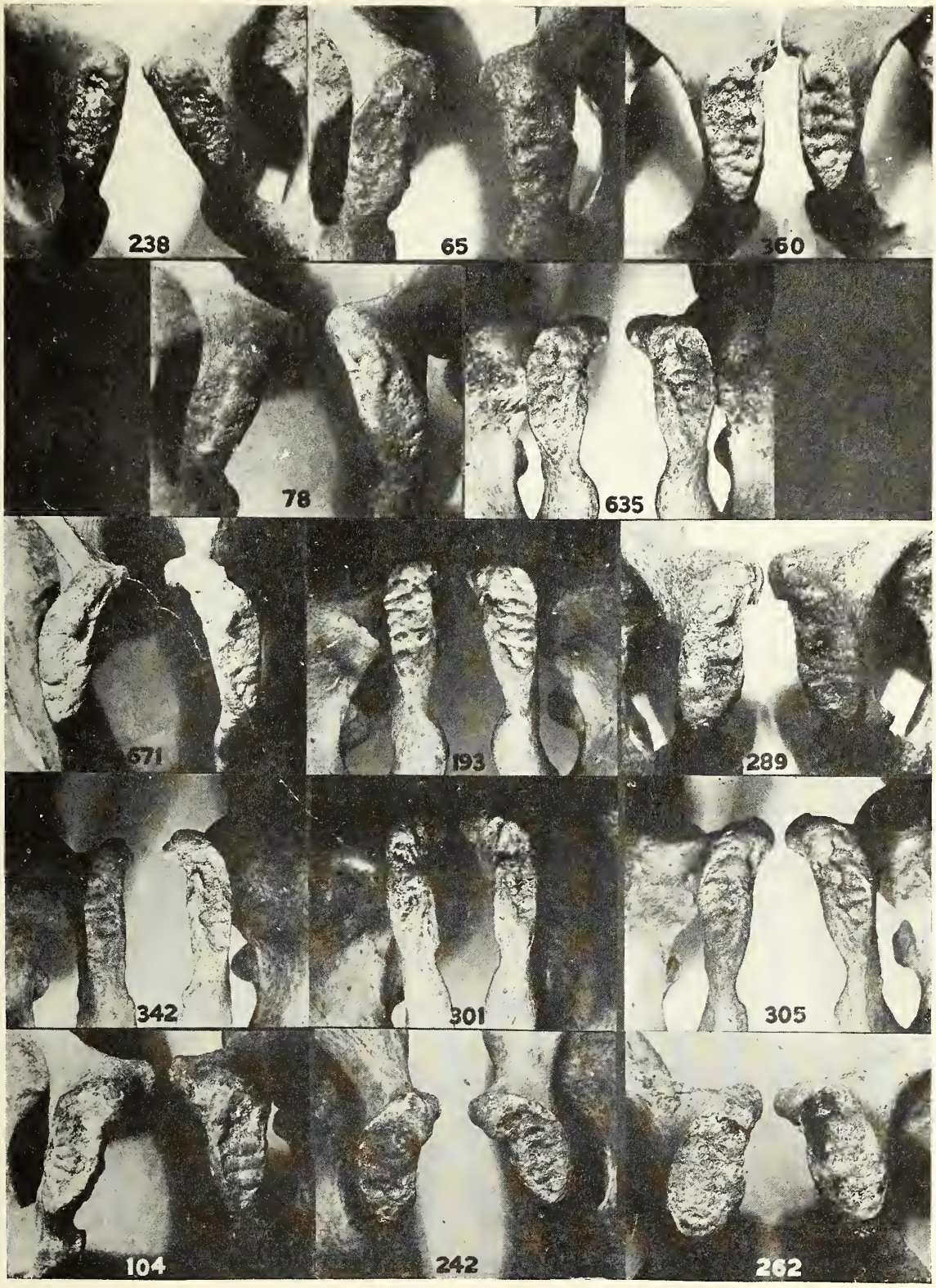
Plate I.



Figures: Uppermost row — Figs. 4, 5, 6; second row — Figs. 7, 8; third row — Figs. 9, 10, 11; fourth row — Figs. 12, 13, 14; lowest row — Figs. 15, 16.

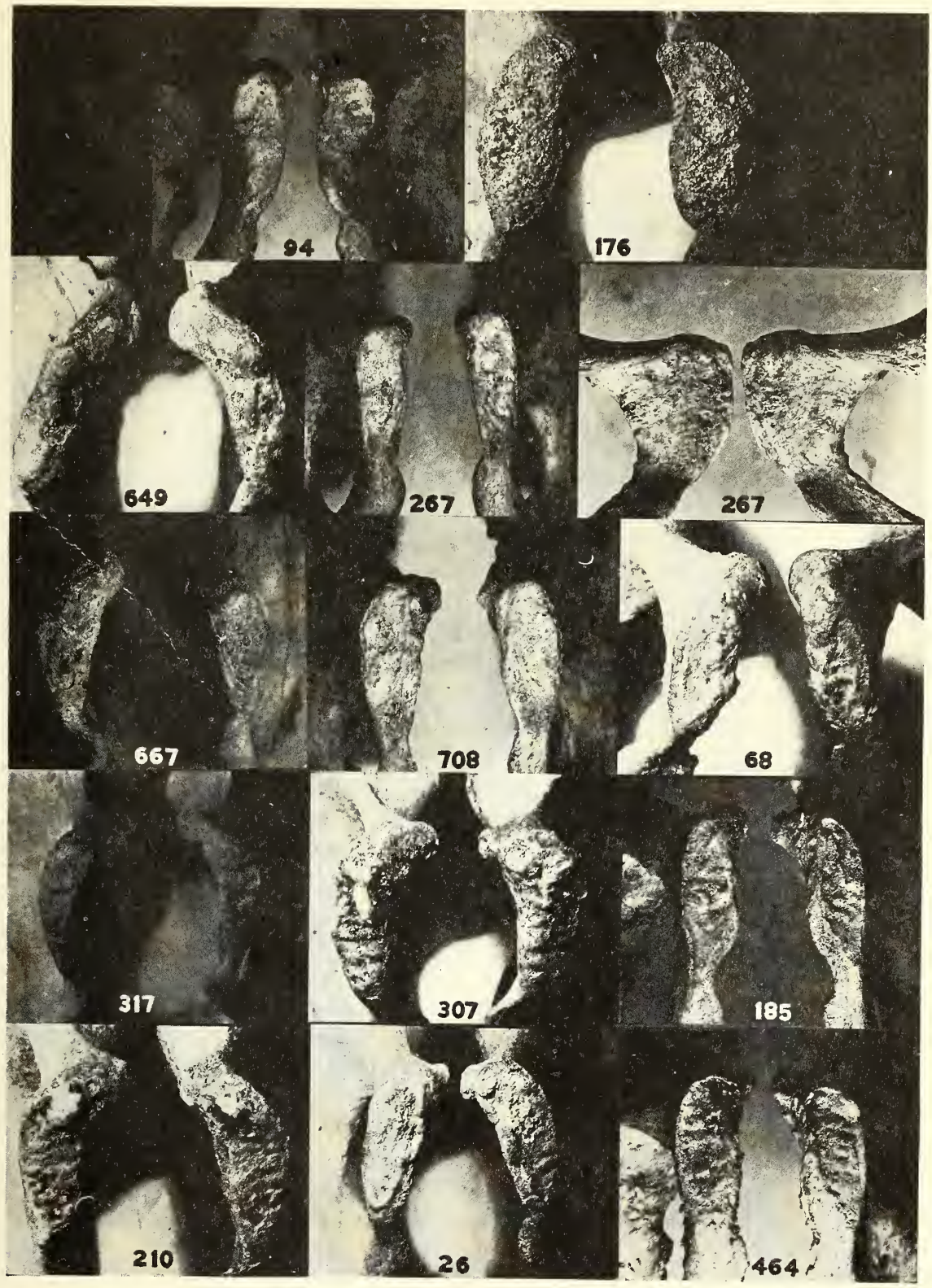
Plate II

Figures: Uppermost row — Figs. 17, 18; second row — Figs. 19, 20; third row — Figs. 21, 22, 23; fourth row — Figs. 24, 25, 26, 27; lowest row — Figs. 28, 29, 30.



Figures: Uppermost row — Figs. 31, 32, 33; second row — Figs. 34, 35; third row — Figs. 36, 37, 38; fourth row — Figs. 39, 40, 41; lowest row — Figs. 42, 43, 44.

Figures: Uppermost row — Figs. 45, 46; second row — Figs. 47, 48, 49; third row — Figs. 50, 51, 52; fourth row — Figs. 53, 54, 55; lowest row — Figs. 56, 57, 58.



Figures: Uppermost row — Figs. 59, 60; second row — Figs. 61, 62, 63; third row — Figs. 64, 65, 66; fourth row — Figs. 67, 68, 69; lowest row — Figs. 70, 71, 72.

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OBSERVATIONS ON AGE CHANGES IN THE SCAPULA

A Preliminary Note

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In 1920 while further studying scapular character variations, through the courtesy of Prof. T. Wingate Todd (Hamann Museum, Department of Anatomy, Western Reserve University), the writer became impressed with a series of changes in the scapula, which appears to be intimately associated with advancing years after maturity of the bone. The human skeletal material in the Hamann Museum is exceedingly valuable for the investigation of bone-age changes in general. It comprises at the present time approximately 750 complete skeletons ranging from birth to 88 years, of known age, sex and stock, and it is growing at the rate of 100 such skeletons a year. Data on age, sex and stock are accessible in all, and data on clinical history, as well as clinical or anatomical causes of death, are accessible in a large number of these complete skeletons.

The scapula is a bone peculiarly adapted to the study of skeletal age changes in any age period. In the first place, its several centers for ossification, uniting in various parts of the bone in sequence at different ages and finally producing an adult scapula in every detail by approximately the 22nd year of life, give to this bone peculiar importance in estimating the bone age of skeletal material during growth periods up to maturity. In the second place, its numerous anatomical and architectural characters, (each of which shows wide variation) its thickened borders limiting its greatly thinned body, its angles, its spine and acromion, its coracoid process, its glenoid, its clavicular facet, its relative freedom from weight influences, its relation to a number of muscles and its peculiar vascular supply, all combine to give to the scapula definite values in studies of skeletal age changes during advancing age periods after the 25th year of life. Regardless of whatever values the scapula may disclose through further investigations, we must not forget that it is only one of many skeletal features showing the ravages of time. Therefore, its worth as a "time-marker" should only be evaluated in connection with other bones and when possible with other tissues.

In a survey of age changes shown in scapulae, it is found that several important features must be investigated and discussed. The relation of the changes identified with age to the type of scapula from birth onward, to certain scapular variations, to human stock, to sex and possibly to disease, must each, in due course, receive attention. The reasons for considering age changes in relation to possible stock, sex and disease differences are obvious, but one would ordinarily suppose that no valid reasons could be given for considering age changes in relation to scapular variations and types, yet such relations are probably equally important. In this connection, attention is called to the writer's communication on "The Types of Scapulae" (American Journal of Physical Anthropology, Vol. IV., No. 2, p. 111.) in which is pointed out certain morphological differences present in the convex, straight and concave types. The writer has secured some data in reference to age changes on 589 pairs of scapulae, embracing convex, straight and concave types from white and negroid stock in the Hamann Museum, and he has more intimately studied the age changes in 139 pairs of scapulae of the convex type from the white males, ranging in years from 18 to 88. It seems advisable thus early in the investigations to define and describe in outline some of the gross features in the scapula which show relation to age after maturity.

SCAPULAR STRUCTURES INVOLVED IN AGE CHANGE PROCESSES

Age changes in scapulae appear to be manifestations of two diametrically opposed processes: the one an ossification process; the other an atrophic process; both occurring after maturity of the bone. The chief structures which show age changes attributed to an ossification process with advancing years are: (1) The articular cartilage in its relation to the bony glenoid margins and possibly also, in the old, of the Labrum glenoidale in its relation to the articular cartilage; (2) The cartilaginous structure covering the margin and surface of the clavicular facet, and possibly of the inter-articular cartilage and joint capsule; (3) The under surface and tip of the acromion in their relation to the coraco-acromial ligament, to the subacromial bursa and to other contiguous structures; (4) The trapezial smooth surface at the base of the spine, and possibly its relation to the trapezial bursa wall; and (5) The cristae in their relation to subscapular intermuscular septa.

The structures which show age changes attributed to an atrophic process discernible mainly in the thinned body of the bone are:

(1) Diminution and eventually loss of surface vascularity; (2) Diminution and alteration in deep vascularity; (3) The occurrence of localized areas of bone atrophy; (4) A buckling or pleating of the thinned body mainly of its dorsal surface above and below the spine, and (5) Distortion of the thinned body mainly below the spine.

Age changes attributed to ossification are equally discernible in scapulae whether fixed (i.e., embalmed) or unfixed. If, however, the bones have been macerated without previous fixation (embalming), the picture of the changes in superficial and deep vascularity is altered, but the other features incident to an atrophic process are readily discernible in fixed and unfixed bones. With the protocols of scapulae to be submitted in the final paper on changes attributed to age the specific differences depending upon fixation and non-fixation will be pointed out. The following outline of definitions and descriptions of gross age-change features is based solely on bones from bodies adequately "fixed" for dissecting purposes.

AGE CHANGES ATTRIBUTED TO AN OSSIFICATION PROCESS AFTER MATURITY

I. Glenoid lipping implies any degree of ossification, in whole or in part, of what appears primarily to have been the articular cartilage in its relation to the glenoid margins or to the immediately adjacent surfaces. Depending upon the bone age of the individual, the lipping may involve the ventral, inferior, dorsal or superior margin and usually in the order named or it may involve the entire marginal surface. When the entire glenoid marginal surface shows lipping it may be rather uniform or it may be distinctly irregular. The lipping usually begins, in the early thirties at the notch or depression which is located at the junction of the upper and middle thirds of the ventral glenoid margin (Pl. I., No. 535). The lipping may be slight, moderate or marked. When it involves the entire marginal surface, it may be flaring, broad at the top thus greatly increasing all original glenoid diameters (Pl. I, No. 551) or it may have nearly vertical walls, increasing the depth of the original bony glenoid cavity (Pl. I, No. 535). In some bones especially those with flaring glenoid margins, the original bony margins seem to be encased, as it were, in new bone (Pl. I, Fig. 551). Rarely the lipping may invade, in part, the articular cartilage near any portion of the glenoid margin. No difficulty should be experienced in recognizing the lipping, if one remembers that at maturity the bony glenoid margins are nowhere roughened, sharpened or elevated. The margins at this

period are relatively smooth and everywhere more or less rounded; less so, however, at the ventral margin than at any other point. When lipping is present, it is easily detected by vision and touch, and when extensive also by transmitted light. Holding a margin of a glenoid in front of a window or an electric-light bulb, one often notes that the ossified cartilage is translucent, and there is often a definite line of demarcation between the lipping and the former bony margin. Whether in pre-senile and senile scapulae the Labrum glenoidale becomes involved, can be determined only by further study.[1]

II. Clavicular facet lipping implies ossification of the cartilage covering the margins and surface of this facet and possibly also of the inter-articular cartilage and joint capsule. When lipping is present, it is seldom uniform, and in some cases it involves the entire margin (Pl. II, No. 535 lower). In the old and relatively old, there is often a marked deformity of this facet, not only of its margins but likewise of its articular surface. When such exists, it is strongly suggestive of a former osteo-arthritic process. Nevertheless, the deformity has been found thus far only when associated with other definite scapular age changes.

III. Acromial under-surface and tip ossification implies the presence of an elevated *plaque* of bone varying in form, size and thickness, situated on the under-surface of the acromion within the area bounded by the outer margin of the acromion and a mesially curved line beginning at the metacromion and ending just lateral to the clavicular facet (Pl. II, Nos. 806, 535). It often prolongs the acromion tip from 2 mm. to 8 or more, and whenever large, usually extends beyond the outer deltoid margin (Pl. II, Nos. 806, 535). It may be elevated 2 mm. or more above the under-surface of the acromion. It is often oval or nearly so, and when extensive, its long axis usually parallels that of the acromion (Pl. II, Nos. 806, 535). Its long axis varies from 5 to 35 mm. and its transverse axis from 4 to 25 mm. When it is prolonged beyond the tip, it parallels

[1] R. Fick (Bardeleben, Handbuch der Anatomie, Gelenke I p. 169) states that the cartilage covering the middle of the glenoid cavity is 1.3 mm. thick, it increases in thickness toward the margins and at the inferior margin it is 3½ mm., at superior ventral and dorsal margins 2½ mm. thick. My own measurements of marked vertical lipping of the entire glenoid margin correspond closely with Fick's measurements of the cartilage covering the bony glenoid margins. While the Labrum glenoidale is in intimate relation with the greater portion of that part of the articular cartilage covering the bony glenoid margin, it, however, appears that the structure primarily involved in the lipping is the articular cartilage covering the glenoid margin of the adult bone.

the general direction of the coraco-acromial ligament (Pl. I, No. 535 and Pl. II, No. 535). Its under-surface is relatively smooth and often concave. Its dorsal surface, when it extends beyond the tip, is usually convex, and the tip of the plaque is often serrated or digitated (Pl. II, No. 535 lower). Its extension of the acromion tip and its direction are strongly suggestive of ossification of the acromial portion of the coraco-acromial ligament in its relation to the tip and under-surface of the acromion. But the limitation of this plaque to the under-surface of the acromion in some cases and its variation in form, size and thickness strongly suggest the involvement by ossification of the subacromial bursal wall and possibly of other contiguous structures.[2]

V. Trapezial smooth surface ossification is defined as granular or scale-like proliferation involving the triangular smooth surface at the base of the scapular spine. When such exists this surface becomes uneven and roughened. It is easily discernible by sight and touch; often symmetrical in degree and form, although it may be confined to one surface (right or left) alone.

VI. Cristae ossification implies relative increase in cross-section and roughening of their surfaces, especially of their apices (Pl. III, No. 172 and Pl. IV, 285 top). In the new-born, the cristae are seldom even indicated on the bone. They are relatively small at the 12th year, and become more definite in succeeding years to maturity, at which period they are usually well marked, but their apices at this period are relatively smooth. Even at maturity and afterwards they vary greatly

[2] This plaque has been noted in every considerable collection of scapulae, representing various human stocks thus far examined by me. I have also found it in other primates, i.e., gorilla, orang and chimpanzee. Until the present study I had interpreted it as a rather frequent morphologic variation. No reference to it as yet has been found in the literature. The evidence thus far secured which seems to justify the presumption of an age factor in its interpretation is as follows: (1) that it is not a vestigial structure either in an ontogenetic or in a phylogenetic sense; hence it is a structure devoid of former or present function; (2) that when of considerable size, as in No. 535, Pl. II, it may interfere, more or less, with shoulder-girdle function; (3) that it is invariably associated with some of the age changes defined and described in the text; (4) that neither in man nor in other primates has it thus far been found in young and relatively young, but invariably in old and relatively old bones; and (5) that it is indicated as early as the 30th year in human scapulae, increasing in size and frequency of occurrence in succeeding age periods, although it may be either rudimentary or absent even in senile bones. The precise structure or structures involved in the genesis of the plaque; what relation, if any, its presence may bear to pathological processes in general, aside from those incident to age, are problems for further investigation.

in number, length and cross-section. They often show marked asymmetry in these particulars right with left in age periods before, at, and after maturity. Moreover, variation in number, size and symmetry of the cristae appears to be in no way dependent upon right handedness, left handedness or muscular development of the individual. Large and strong bones may show rudimentary and markedly asymmetrical cristae; whereas small and weak bones may show large and nearly symmetrical cristae. Whatever their degree of development and symmetry at maturity may have been, they appear to become broader at their bases, more prominent and their apices more roughened or serrated with advancing years. These features, particularly the degree of roughness of the apices, are taken into account in estimating the bone age of scapulae after maturity.

AGE CHANGES ATTRIBUTED TO AN ATROPHIC PROCESS AFTER MATURITY

I. Surface vascularity is defined as visibility to the naked eye of the vessels which seemingly lie just within the outer layer of compact tissue about the dorsal and ventral surface of the body and the bridge of the spine of the scapula. Surface vessels in properly "fixed" specimens are more or less numerous during the developmental periods from birth to maturity, but diminish in visibility and finally disappear as age advances.

II. Deep vascularity is defined as visibility of vessels to the naked eye as may be noted in the body of a bone to transillumination, as from a window or electric-light bulb. Photographic transillumination of a pair of scapulae from an individual aged 13 years is shown in Pl. V, No. 633. It is noted that the vascularity is poorest in the normally thinned areas of the body, namely, above the spine, just below the spine, along the axillary border and extending along the vertebral border in the inferior-angle region. It is richer along the vertebral border above the inferior-angle region, in the area near the center of the body below the spine, and still richer in the areas adjacent to the spine above and below it, and along the margins of the normally thinned areas. Deep vascularity is richest, as is surface vascularity, in periods of greatest growth, as at pubescence, but diminishes in succeeding life periods. It becomes less in the early twenties, as shown in Pl. V, No. 680 which is from a photograph of deep vascularity by transillumination in a pair of bones at 23 years for comparison with Nos. 633, 115 and 285. In advancing years after maturity of the scapula, deep vascularity continues to be-

come less and less visible, but in no period in bones thus far examined does it wholly disappear. In Pl. VI, No. 115 showing transillumination of a pair of scapulae of a white male, age 88 years, small vessels were still visible just above and below the spine, but were most marked in the glenoid region below the spine. Deep vascularity may be diffuse, a characteristic of bones to trans-illumination prior to, at, or somewhat after maturity (Pl. V, Nos. 633 and 680). In bones after maturity alteration in diffuseness of deep vascularity, when present, is called patchy, and the degree of patchiness may be slight, moderate or marked (Pl. IV, No. 285 and Pl. VI, No. 115). With advancing years the size of vessels and their visibility to the naked eye becomes appreciably less, disappearing first from the normally thinnest, relatively most poorly vascularized areas, but persisting in number and degree in the well vascularized areas of the bone, as along the root of the spine, above and below it, and especially in the glenoid and vertebral-border regions just below the spine. Even in the scapulae of No. 115 a few small vessels are still discernible (not shown in the photograph) in the glenoid and vertebral-border regions below the spine and in the persistent cancellous tissue near the middle of the body below the spine. The transition from diffuse to patchy vascularity and its degree of patchiness appears to be intimately connected with the feature next to be described, which is to me the most striking scapular age feature connected with advancing years, namely, the presence of what are here designated *atrophic spots*.

III. Atrophic spots may be defined as localized, discrete or coalescing areas of bone atrophy. They are discernible to the naked eye in the body of the scapula by direct- and trans-illumination, and to palpation. I have already referred to the diffuse nature of deep vascularity prior to, at, and somewhat after maturity and to the occurrence of varying degrees in patchiness as indications of advancing years. Atrophic spots do not occur without some degree of patchiness in vascularity; hence slight patchiness is probably the forerunner of these spots, and may be construed as an early manifestation of the atrophic process which seems to underlie them. In giving an outline description of atrophic spots, let me here recall the original observations on the scapulae from skeleton No. 285 of a white male age 45, dying of pulmonary tuberculosis (Pl. IV, No. 285). While examining the borders for variations and translucency, it was noted that the bodies of this pair of "convex" scapulae appeared to be *patchy*, spotted, "moth-eaten" and particularly so in the thinned areas above and below the spine. When viewed with direct

light some of the spots were found to be depressed (excavated) below the level of the adjacent surface of the bone, thus sharply delimiting them from surrounding tissue (Pl. IV, No. 285 top). Those thus depressed below the surface were thin to palpation, almost as thin as parchment. To trans-illumination they were pale and deficient in pigment in part, and the paler areas were pearly, granular, amorphous, in appearance not unlike "dissolving sugar in weak tea." The more pigmented areas within such a spot were slightly thicker and less translucent, and connected with its adjacent border by a bridge or bridges of persistent cancellous tissue. To low power magnification (10 diameters), the definitely "granular" portion of such a spot was found to be poorly vascularized; only a few minute vessels could be seen; whereas, in the denser interior and connecting bridges, the vessels were larger and more numerous. Examination of a number of scapulae from individuals under 45 years disclosed either absence, smallness or infrequency of these spots; whereas, the scapulae of a number of individuals beyond 45 years usually disclosed them in greater number, size and degree. It was also found that there was an intimate association between the number, size and degree of "spots" and the patchiness in deep vascularity. All these findings were true in a general way, irrespective of the cause of death, though it was occasionally found on consulting the records, that in individuals who had died from exhausting diseases (tuberculosis, syphilis, cancer, etc., etc.) the scapular bone age was somewhat greater than the chronological age. The scapular bone age of skeleton 285 (Pl. IV) was at least 7 years greater than the chronological age, and Dr. Todd, in considering bone age features of other bones of this skeleton found some of them to be beyond the chronological age. Following these initial observations other scapular features herein defined and described were found to be associated with advancing years. Varying numbers and degrees of these features are invariably present in scapulae disclosing atrophic spots. Moreover, further observations have shown that similar "spots" are present in scapulae of other mammals whose skeletons show senile changes, and they are also present in senile thin bones generally, analogous to human shoulder blades in their proportions of cancellous and compact tissues. I must here emphasize the fact that not every area of a scapula showing localized translucency, whatever the size or degree, is an atrophic spot. In addition to increased translucency there must be a localized alteration in the vascularity and in the structure of the bone. In general it may be said that the "atrophic spots" vary greatly in size (3 mm. to 10 or more) and

in the early stages have irregular patterns, but in later stages tend to become ovoid or circular. They are discrete in the early stage, but in the later stages of development they coalesce, and in some senile bones these coalescing atrophic spots involve the greater portion of the body. In such bones, the bodies become very thin in the greater part and the cancellous tissue in the thinner areas of the bones practically disappears. Even the cancellous tissue adjacent to the borders of the bone is often invaded by spots. Finally in very senile bones and in those whose bodies are normally very thin, yet showing senile changes, oval defects varying in diameter from 2 to 5 mm. occur in the extremely thin areas of the spots. As may well be imagined, because of parchment-like thinness of advanced atrophic spots, they often show irregular fragmentation. The round or oval defects in atrophic spots must, of course, be differentiated from congenital membranous defects (very rare variations) and pseudo-membranous defects often found in scapulae following body fracture. True and pseudo-membranous defects are differentiated from atrophic spots by their larger size, thicker margins and by the absence of alterations in vascularity and in bone structure.

IV. & V. Buckling or Pleating and Distortion may best have a common description (Pl. III, Nos. 427 and 172). Each of these age features appears to depend primarily upon altered vascularity leading to irregular bone absorption (atrophy) especially of the cancellous tissue. The absorption, mainly of this tissue, seems to underlie the alterations in contour of body surfaces and distortion of the entire thickness of the body of the bone. Buckling or pleating implies alteration in form of the originally relatively smooth body surface, and mainly of its dorsal surface. When present the body is no longer smooth, but it is thrown into folds, coarse wrinkles or pleats. It is usually present in some degree in the early thirties, and often makes its appearance as a single elevated buckle, wrinkle or pleat running transversely to the long scapular axis in the superior-angle region (see Pl. III, No. 427 left). At about the same age period less definite pleats make their appearance about the dorsal surface of the body below the spine, and parallel in a general way the direction of the cristae. Buckling or pleating is seldom a very prominent age feature if the body of the bone is thick. It is, however, a frequent age feature in most bones, and it increases in degree usually with succeeding age periods after 30.

Distortion implies deformity or warping of the entire thickness of the body of the scapula occurring mainly below the spine (see Pl. III, No. 172). It is seldom found in any degree prior to the 40th year. It is

never marked in those exceptional bones having very thick bodies. Buckling or pleating and distortion in fixed and unfixed scapulae are present, whatever the form of maceration may have been. Moreover these age features are usually present in recently dissected scapulae, provided their possessors have attained sufficient age.

GENERAL CONSIDERATIONS

The foregoing outline of the gross features related to age in scapulae after maturity is by no means comprehensive. Those defined and described are the most constant, and are, therefore, the most dependable in estimating the bone age of a scapula. Among the least constant scapular age changes, yet not without value, may be mentioned:—the unusual roughening of certain muscle surfaces, processes and lines (Teres major and minor, Infraspinatus, Deltoid, Trapezius, the field on the vertebral border in the inferior-angle region occupied by the lower fibers of Rhomboideus major in their relations to the fibers of the Serratus anterior, and of the infra-glenoid process); increased translucency of some or all of the borders, the bridge of the spine, the acromion, glenoid and coracoid; the gradual absorption of the relatively thick, often highly pigmented cancellous tissue along the cristae and in the several border regions; the extreme lightness of old bones when compared with young ones of approximately similar dimensions; and the occurrence of atrophic spots in the spine-bridge window of those bones with normally thin windows.[3]

Any one of the above described features, except alterations in deep vascularity, may be absent at an age period in which one might expect to find it. Again, the scapula may be older in bone age than in chronological age, or it may be younger than the chronological age of a given individual. Todd has emphasized these findings in his studies of the Pubic bone.[4] Moreover, everyday observations show that among individuals of the same stock and general environment, some are older and others are younger than their years, as we judge them by their

[3] The increasing translucency of the thicker, as well as of the thinner, portions of the scapula and the decreasing weight usually step by step with advancing years leads one to infer that the atrophic process is not limited to the normally thinner portions of the bone. Whether this inference be founded in fact, and if so, how extensive the atrophic process may be, are problems for further investigation. An x-ray plate of the same scapulae shown in pl. VI from skeleton 115 (white male, 88) revealed definite areas of absorption (atrophy) in the left bone, in the interior of the inferior-angle region.

[4] Todd (T. Wingate), Age Changes in the Pubic Bone. *Am. J. Phys. Anthrop.* 1920, III, No. 3, 286; also 1921, IV, No. 1, 1 *et seq.*

general appearance and reactions. Again, exhausting diseases may advance the bone age of a given individual just as it may advance the age of other tissues; hence we should not be surprised to find, indeed, we should expect to find the registration of advanced skeletal metamorphosis in some cases. But these findings are merely the exceptions to the general rule. Just as Todd has shown in his studies on the Pubic bone, so do my studies thus far on the scapula show that in most individuals there is a close agreement between scapular bone age and chronological age. How close this agreement may be, and what are the usual combinations of scapular features identifiable with each age period await further investigation.

SUMMARY

(1) The scapula is peculiarly adapted to the study of skeletal age changes in any post-natal period, but its worth should be evaluated in connection with age changes in other bones.

(2) The age changes in the scapula outlined in this note appear to depend upon two diametrically opposed processes; the one, an ossification process; the other, an atrophic process, and both occur after maturity of the bone.

(3) Not all of the structures involved in the ossification process are known at this time. Further investigations are necessary to identify them. Moreover, histological investigations are necessary to determine more closely both the nature and the extent of the ossification and atrophic processes.

(4) The scapular changes related to age must be further investigated in reference to the type of scapula, to scapular variations, to human stock, to sex and to disease.

Grateful acknowledgment is due Dr. Todd for the encouragement, the criticism and the many courtesies extended while working in the Hamann Museum, and thanks are due to Miss Harvey for many photographs some of which are used as illustrations.

NO. 535,

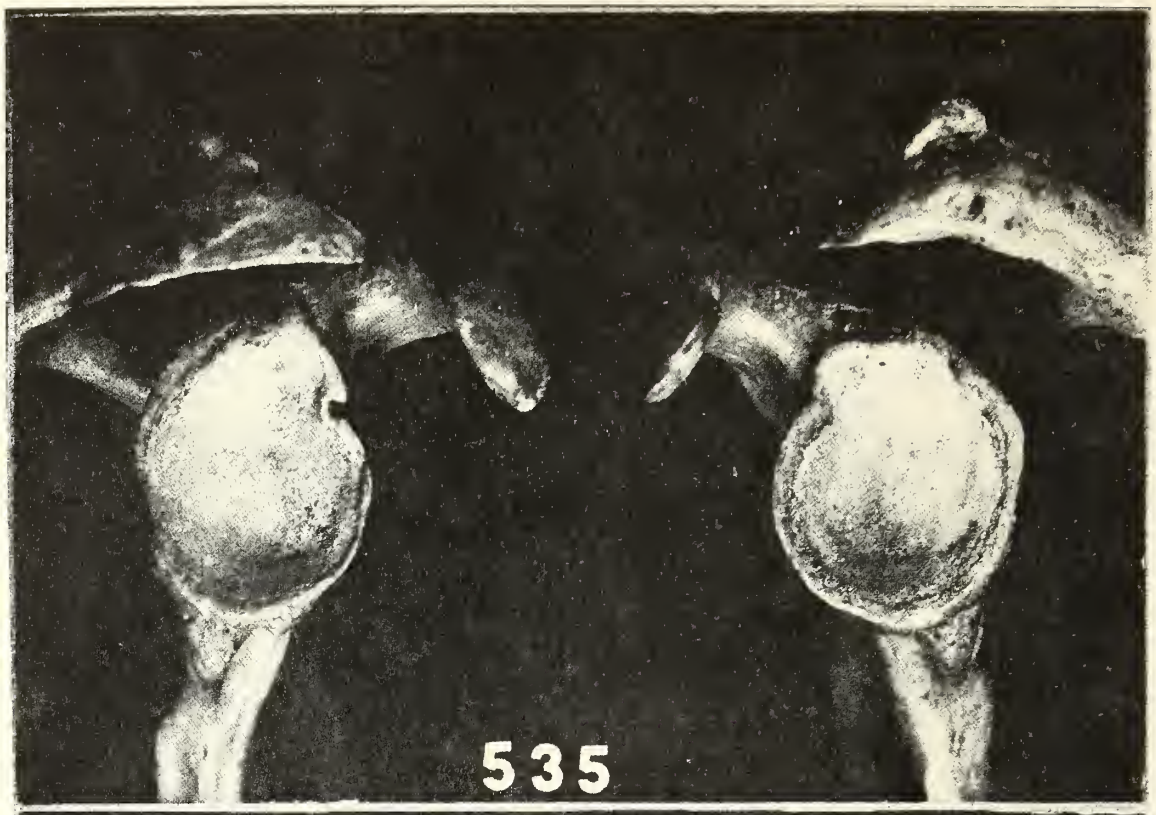
Pl. I. A view of scapulae No. 535 showing the deltoid margins of the plaques in relief and their general direction, paralleling that of the coraco-acromial ligament. Note the rather marked vertical glenoid lipping, also practical obliteration of glenoid notch by lipping on the left bone.

NO. 551, Pl. I.	Marked flaring lipping of entire glenoid margin with obliteration of glenoid notch L. and R. Note the encasing effect of lipping upon original glenoid margin, especially ventrally right and dorso-superiorly left. (White male, 60 years.)
NO. 806, Pl. II.	An elevated, oval plaque of ossification (left more than right) of the acromial undersurface, without tip involvement. The plaque extends slightly beyond and parallels the deltoid margin. (White male, 35 years.)
NO. 535, Pl. II. (mid)	Unusually extensive oval, cup-shaped, elevated and rather symmetrical plaques involving undersurface of acromion and tip in the ossification. Each plaque measures approximately 22 x 35 mm., prolonging the original acromion tip 17 mm. and extending beyond the deltoid margin 5 mm. The distance between the original acromial tip and coracoid is reduced approx. 13 mm. Thickness of plaques at acromial tip is approx. 6 mm. (White male, 50 years.)
NO. 535, Pl. II. (low)	Another view of 535. Note the serrated margins of the plaques and the reduced distance of the prolonged acromial tips from coracoids and the relation of the plaques to the greatly enlarged, markedly lipped and roughened clavicular facets.
NO. 427, Pl. III.	A dorsal view showing atrophic spots, buckling or pleating and distortion. Note particularly the transverse pleat on body of left bone above spine beneath which is a circular, excavated fragmenting atrophic spot. (White male, 65 years.)
NO. 172, Pl. III.	A ventral view showing prominence of cristae and roughening of their surfaces, also pleating and distortion of body. Cause of death—gastric carcinoma. Note in sub-scapular fossa on left bone a small tumor, possibly metastasic. Bone age about 10 years greater than chronological age. (White male, 50 years.)
NO. 285, Pl. IV. (top)	A ventral view of scapulae showing advanced discrete, coalescing and excavated atrophic spots in bodies below spine; more definite in right bone. Cause of death pulmonary tuberculosis. Bone age about 7 years greater than chronological age. (White male, 45 years.)
NO. 285, Pl. IV. bottom)	A transillumination view of scapulae from dorsal aspect. Note general patchiness and atrophic spots in whiter areas.
NO. 633, Pl. V.	Deep vascularity distribution shown in transillumination as described in the text. (Colored, female, 13 years.)
NO. 680, Pl. V.	Deep vascularity by transillumination. Note diminution in deep vascularity in comparison with Fig. 633. (White male, 23 years.)

NO. 115,
PL. VI. Almost complete disappearance of deep vascularity to transillumination for comparison with Nos. 633 and 680, Pl. V. Note distinct patches of persistent cancellous tissue near middle of bodies below spine. (White male, 88 years.)[5]

[5] Nos. 633, 680, 285 and 115 from transillumination photographs require a word of explanation. The technical details were as follows: The bones were placed on the transparent object-plate dorsal surfaces uppermost as in No. 427, Pl. III, and plasticine was then used to exclude the light from around their margins, the source of light being a 60 Watt mazda beneath object plate. The camera was centered above the bones and focused. Obviously only the more or less translucent areas can be shown with such technique; hence the absence of spines, acromions, borders, glenoids, etc. in figures, but borders and spines are outlined for orientation. The thinner portions are the more translucent and are shown in the lighter areas; whereas the thicker or denser, less translucent portions, are the darker areas in figures. The positions of the spines and cristae and of the denser areas of the bodies adjacent to them shade down to black. A stronger illuminant fogs the plate and the exposure in radiography is difficult to time so that the radiographic results are too poor for adequate reproduction (personal communication from Miss Harvey).

PLATE I



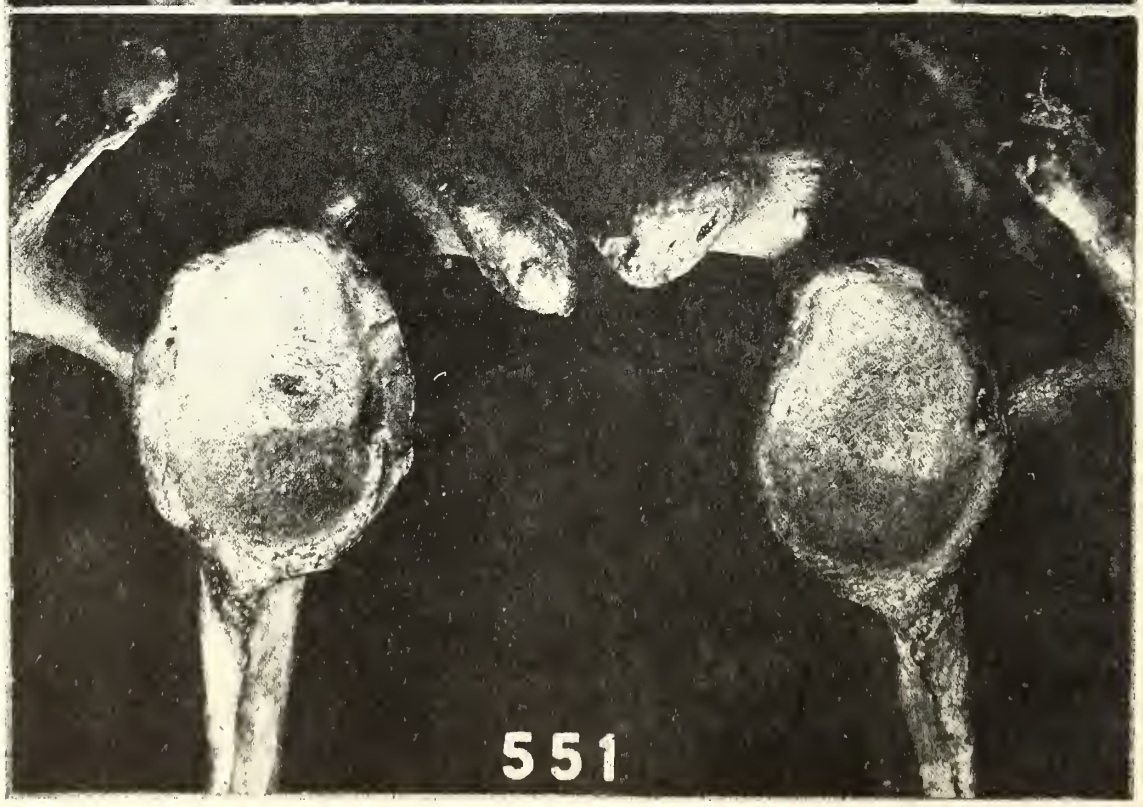


PLATE II

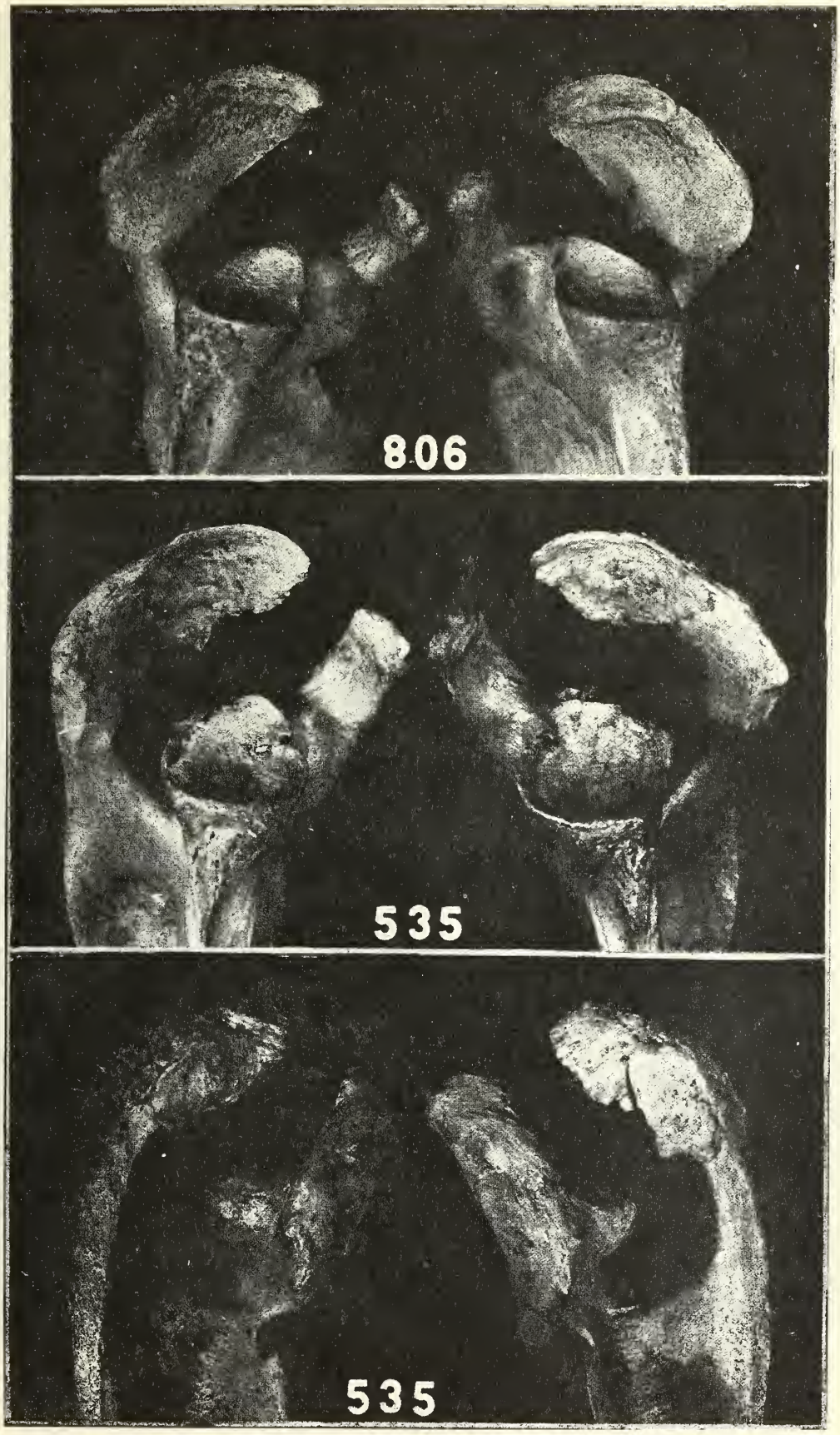


PLATE III

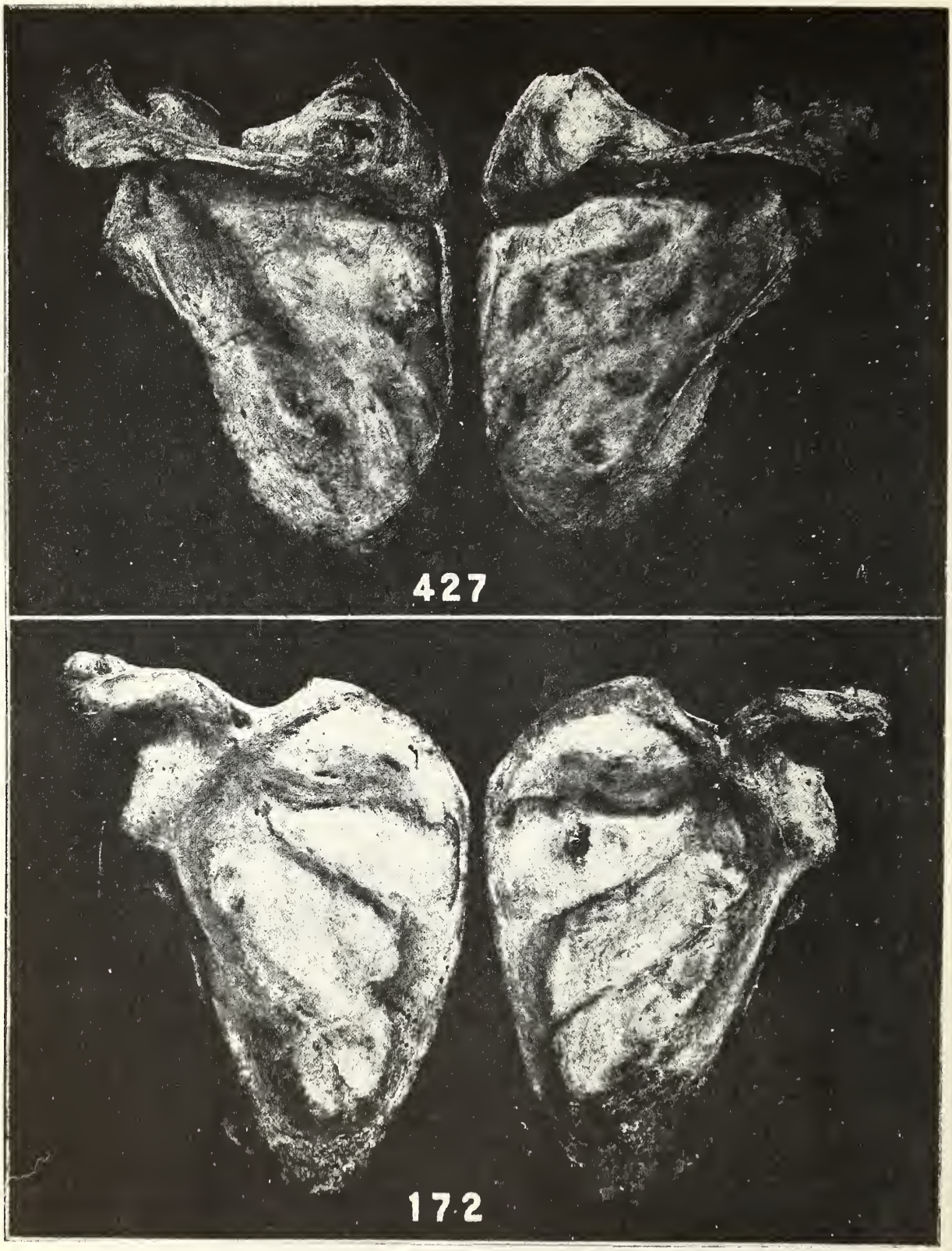


PLATE IV

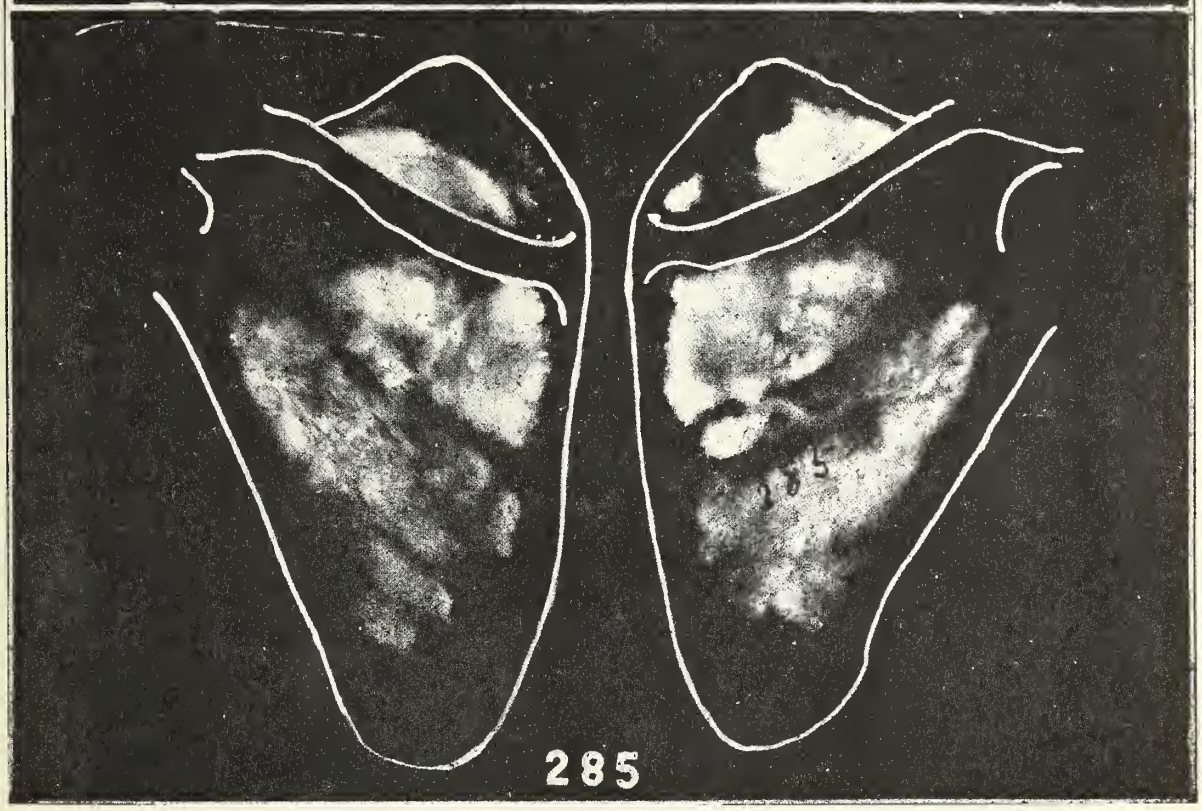


PLATE V

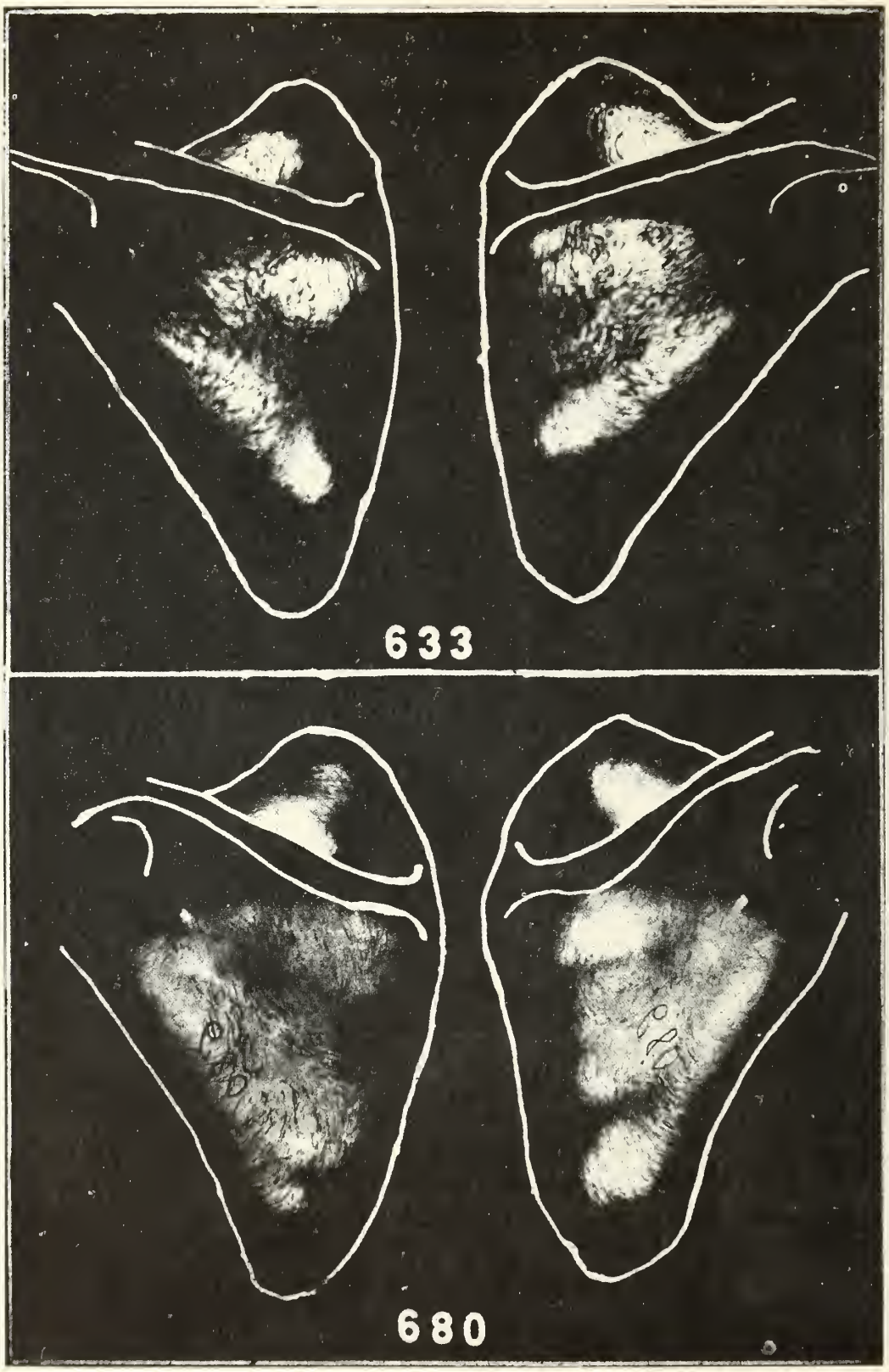


PLATE VI

CRITICAL COMMENTS ON CRANIAL SUTURE CLOSURE

Space is available to reprint only two of the series of four studies by Todd and Lyon on suture closure. The others are:

III. Endocranial closure in adult males of Negro stock. Am. J. Phys. Anthrop., vol. 8, 1925, pp. 47-71.

IV. Ectocranial closure in adult males of Negro stock. Ibid., pp. 149-168.

The omission of these papers does not signify that race differences are unimportant in connection with the assessment of skeletal age. Actually, it is always important to keep in mind the race of the individual skeleton being identified, for race may carry with it the connotation of a particular socio-economic background. The latter, rather than race in the usual sense, may be responsible for physiological changes failing to keep pace with the established chronological norms.

The racial aspect of this subject has received further consideration recently by Ronald Singer of the Department of Anatomy, University of Cape Town (J. Forensic Med., vol. 1, 1953, pp. 52-59). After studying the skulls of 100 Cape Coloureds, 190 Bantu, 50 White Germans, 60 North American Indians, and 30 Eskimos, Singer concludes that "an assessment regarding the precise age at death of any individual, gauged only on the degree of closure of the vault sutures of the skull, is a hazardous and unreliable procedure" (p. 59). This statement should be kept in mind in reading the papers here reprinted.

W. Montague Cobb is the only one so far to study facial suture closure in connection with closure of the vault sutures (see abstract in Am. J. Phys. Anthrop., n.s. vol. 10, 1952, p. 256), but his findings are not yet available.

Reprinted from the American Journal of Physical Anthropology, Vol. 7, No. 3, July-September, 1924, pp. 326-384.

ENDOCRANIAL SUTURE CLOSURE

ITS PROGRESS AND AGE RELATIONSHIP

Part I.—Adult Males of White Stock

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HISTORICAL INTRODUCTION

When, in 1641, Thomas Bartholinus republished the lectures and views of his father, he gave us not merely a thoughtful and stimulating treatise on Anatomy fresh, as it were, from the lips of a real investigator but added thereto a synopsis of the current and earlier thoughts upon the subject. For the opportunity to consult first-hand the Fathers in whose writings so much of value is to be found but so largely forgotten through difficulty of approach, this laboratory is indebted to gentlemen like Dr. Weber and Dr. Chamberlin who have presented to the Hamann Museum these rare and valuable sources of information. To return to Bartholinus we find the following stated as the "uses" of sutures (1).

1. To permit free transpiration of the vapors in the brain.
2. For the attachment and suspension of the dura lest it should press upon the soft brain.
3. For the transmission of fibers of the dura through to the pericranium.
4. For the transmission in both directions of vessels carrying nourishment and life to the parts.
5. To diminish the likelihood of fracture of one bone involving also others.
6. To permit more easily the penetration of applications from the exterior.

The hand of tradition is clearly seen in current views upon the sutures when one ponders the six "uses" just enumerated. It is true that number six and to a less extent number five have faded from the modern imagination but numbers two, three and four remain little altered. Number one has undergone considerable change but this change is more in conception of the details than in fundamental principle. We still see the publication of monographs as their theme the relation of early racial closure of sutures to the degree of "intellectuality" and the connection between suture closure and shape of the cranium, both of which ideas can be traced back to the works of Hippocrates. Delightful as it would be to follow out in some detail the development of our present beliefs concerning the sutures, to trace the constancy of these conceptions through the Renaissance to the Anatomists of Antiquity and thereby to realize more fully than we are apt to do the overwhelming influence of tradition, this is really no part of what I have set out to accomplish. I propose to present the facts concerning suture closure and its relation to the racial form and individual contour of the braincase. Those who desire to study this historical aspect of the problem

cannot do better than consult, by way of introduction, the scholarly work of Pommerol (15) published in 1869.

In brief, although ancient authors like Hippocrates, Aristotle and Galen were acquainted with the fact that some human crania show multiplicity of sutures whereas others are almost or even totally devoid of sutures, dog-like as Aristotle has it, the fact that union occurs during life does not appear in literature until Fallopius attacked the traditional doctrine in the middle of the sixteenth century. It seems probable however that Fallopius was stimulated to make his observations by his great master Vesalius. At any rate there was rebellion in the air against the classical view that sutures have a close relation with skull form for Sylvius who had once been the teacher of Vesalius, Columbus who like Fallopius had been pupil of Vesalius, and Eustachius all shared the view expressed by Fallopius. Very slowly was this new conception assimilated by the majority of Anatomists and a hundred years later the Bartholins agreed that the relation described by the ancients can be found in but rare instances (1 p. 452.).

According to Bartholin the number and site of the sutures, contrary to the assertion of Aristotle, are the same in both sexes, and unchanged, except rarely, by the form of the cranium. To this Diemerbroek, as quoted by Pommerol, added that deformations take place perhaps during foetal life, perhaps at birth. So far back then must we go for the idea of congenital deformity. Gradually after this time the old Hippocratic views upon cranial form faded into obscurity. But curiously enough they were revived by Lucae and Virchow together with the Hippocratic idea of the relation between suture condition and cranial form, although naturally these latter regarded cranial form as influenced by suture closure which is abnormal in point of time. To use the term of Vesalius, the various "figurae depravatae" described by Bartholin return in the classification of these two writers of the nineteenth century. So striking is the similarity between the views of Hippocrates and those of Virchow, allowing for the lapse of time, that Pommerol gives himself up to the picturesque metaphor of the Father of Medicine and the Father of Cellular Pathology meeting each other across the centuries on the subject of synostosis.

Since the middle of the nineteenth century our ideas of the relation between suture closure and growth of the brain have undergone an inversion so that it is now generally recognized that growth of the brain is a cause rather than an effect of the precise date of suture closure. It is not necessary to press the distinction which will of course be under-

stood throughout the further presentation of this theme. Although fully recognizing this change of view the immediate purpose is a study of the sutures themselves and their union. Just as it is no new thought that some relation exists between shape of cranium and union of sutures on the one hand and development of the brain on the other, so also an impression of racial distinction in suture closure is of considerable antiquity. Pommerol points out that Celsus, in his compendium of medical learning in the first century A. D., refers to the teaching, which be it noted antedates Galen, that crania devoid of sutures occur more readily in warm climates (15). This statement was later clarified by Arranius when he asserted the condition to be peculiar to Ethiopians. Here then we have the germ of a belief that suture closure takes place at a relatively early age in Negroes and other "lower" races. No real advance save that associated with Fallopius has been made since these early times. Winslow and others in the eighteenth century emphasized the analogy between sutural membranes and the diaphyso-epiphysial plane, and soon afterwards Soemmering and Meckel pointed out relationship between state of the sutures and development of the brain.

As regards age of suture union it is useless to dissect closely the unprofitable discussions of the last century, based as they were upon altogether inadequate material of which very few skulls were of well attested age. Fallopius had observed that union occurs and Eustachius had noted that it takes place first in the sagittal suture. In the middle of the nineteenth century union had been observed to occur earlier within the cranium than upon the exterior, and in 1856 Gratiolet enunciated his well known laws regarding the earlier union in Negroes and the precise sequence of closure to which we must revert later on (8). During the famous discussion upon volume and form of the brain in 1861 Broca was unable to draw upon any precise data regarding age of closure but observed that many sutures are still patent in men of fifty and even beyond (5 p. 179). Gradually opinion crystallized into a belief that union begins between forty and forty-five years at least in White Stock (e. g. 17), and upon the evidence of a single male skull of forty-six years Pommerol agreed that closure must commence about forty (15). Topinard had Pommerol's work to fall back upon but in addition had observed as closely as possible other material and is more definite. He notes that the period of union for each suture varies considerably but hazards the opinion that if the sutures are yet patent the individual is thirty-five or less, that commencing closure in the sagittal indicates about forty years, in the coronal fifty years, and that if the temporal be

united it indicates an age of sixty-six or more (23). Ribbe in 1885 had fifty skulls of supposedly known age of which forty were those of White Stock. The earliest occurrence of union among these was at twenty-one years and the latest at fifty-five. Taking the mean he concurred that forty to forty-five is the probable average age of commencing closure (16). As regards age identification by suture union Ribbe did not believe it possible to estimate closer than fifteen to twenty years. Dwight set the age of a cranium showing no suture closure at less than thirty years (6). Dwight's material consisted solely of paupers whose ages were apparently not verified. One cannot tell whether, in many of his cases, the statements regarding closure refer to exterior or interior or both. He regarded the date and order of closure as very irregular and not of much value as an age indicator. However he recognized that the same points are not first involved on both sides and that the inner lambda is often patent after all other areas are united.

All the foregoing observations must be regarded as based almost entirely upon external union which may proceed very differently from internal closure. Parsons and Box in 1905 however began to emphasize the significance of internal union (13) and upon this basis they agreed with Dwight.

Frédéric, in 1906, working under the inspiration of Schwalbe who had himself studied this problem in connection with his investigation of the Neandertal skull, made a very comprehensive examination of suture closure in the collection at Strassburg. Frédéric had at his disposal 255 European crania and 119 non-European skulls all of known age. Of these however only 91 European and 13 non-European crania of both sexes were opened so that the internal surface could be satisfactorily examined (7 Table VII.). Frédéric therefore based his conclusions mainly upon the external condition of the sutures of the vault in the unopened cranium. Into the details of Frédéric's observations it is unnecessary to enter here. He decided that it is not possible to determine the age of any skull by the condition of suture union closer than within one decade and hence gives a table (his Table VIII) showing in percentage form the complete closure of each suture externally and the sutures of the vault internally for each decade. This is not very helpful nor is it encouraging. Hence the whole question of the relation of suture union to age remains an intricate and unsolved problem, hopeless alike in the scattered confusion of the data, in the inadequacy of the material utilized and in the unreliability of the information upon which determination of age has been made.

The articles by Pommerol, Ribbe and Frédéric are the main contributions to this subject so far. Each is excellent in its way but all fail to add much to our real information upon age relations, the two former from lack of material and the last mentioned from method of treatment: Parsons and Box, on the other hand, although they had access to but 82 skulls of known age, inspire the greatest hope. They make the very important observation that no estimate of age should be based upon the condition of ectocranial sutures when the inside of the skull can be examined, thereby indicating their opinion that a more definite relation to age might be obtained from a study of endocranial sutures were such a collection of sufficient magnitude available for review. It is at this point that we take up the work.

MATERIAL AND METHOD OF EXAMINATION

From a historical survey of the problem before us it is plain that little real progress has been made and that a proper investigation of the question postulates three necessary conditions. The material must be ample enough to justify it as a sample of the population studied: if both sexes and more than one race or Stock can be examined so much the better. In addition to sex and race age must be known: hear-say will not suffice; there must be some adequate method checking up the given age so that confidence in its accuracy may be inspired. The crania must be cut so that easy inspection of the entire interior is rendered possible. During the past ten years we have endeavored to fulfil these conditions and although accumulation of a satisfactory sample is tedious and difficult I feel that the material which we shall present is adequate for the determination of at least the general features of suture closure.

Drawing upon the crania of more than 1,000 individuals we have rejected all those of which the age record was imperfect or was later discovered to be fictitious, and all those of which the skeleton was not available for comparative study. The series left to us comprises the crania of 307 male Whites, 58 female Whites, 120 male Negroes and 29 female Negroes, a total of 514 skulls all of known age.* It is not suggested that the female crania in the series are of any independent value but even so small a group is useful as a check upon the age relationship shown by the corresponding males. We shall base our conclusions upon the male White series and shall compare with this standard the con-

*NOTE—These numbers refer to the collection in 1921 when this survey was commenced. The numbers are greatly increased now (March 1924.)

ditions found in the females and Negroes. So far as actual numbers go this collection far outstrips any material hitherto available.

It is unnecessary to dilate upon the precise method of checking up the age record of the individual for this has been discussed in a previous paper (19 pp. 289–292) but since that date we have learned to have much greater confidence in the internal evidence of the skeleton itself upon the age problem. As yet little has been published of the great accumulation of data dealing with skeletal age and its significance in Anthropological work. Graves has set forth a preliminary note dealing with the scapula (9) and Stevenson has presented the evidence for epiphysial union (18). These together with my own researches on the pubic bone form merely a beginning for reference. The harmony which is evident among these studies is also to be found in many other investigations not yet ready for the press. Hence it must not be assumed that these alone form the basis of our conclusions. No effort has been spared to obtain complete satisfaction in the question of age which is so fundamental for all our researches. In brief then we may state that from the point of view of age determination the W. R. U. collection is dependable so far as is humanly possible and much more dependable than the vital statistics upon which actuarial investigations for insurance companies are based.

Like our predecessors we have adopted Broca's arrangement of complication of sutures, degrees of closure and subdivision of particular sutures except that we have followed Frédéric in his inversion of Broca's enumeration of the amount of union. Thus, in our records, 0 indicates no union and 4 complete closure: 1, 2, 3, refer to the amount of union, one-quarter, one-half or three-quarters as the case may be. These schemes are set forth in Frédéric's paper (7 pp. 376, 377, 385). We do not differentiate between union which has progressed half-way along a suture and closure which involves a total of half the length of a suture but is exhibited in separate discrete areas. The scheme of Oppenheim dividing sutures into pattern forms and degrees of excursion we have set aside as too involved for practical use (12). The now accepted subdivision of the sutures of the vault is seen at a glance from Oppenheim's figure or Martin's figure 243 (11 p. 627).

To facilitate the accumulation of data we devised a form which can be filed on the card catalogue system and records the type of each subdivision of every cranial suture and the degree of its closure. Separate sheets are used for external and for internal sutures. At the head of each sheet the following general data are recorded: Number of skull,

race, sex, age, greatest length, greatest breadth, cephalic index, cranial capacity, sites of Wormian bones. Thus we had at hand all the information which we felt might be of service in discussing suture closure. The junior author wrote down upon this form the data obtained from our laboratory records and filled in the condition of the sutures and their union. The completed record was then gone over anew by both authors together and the data checked. Consequently the type of suture and the degree of closure are to be understood as the joint observation of two individuals. Where there was any doubt concerning the amount of union the suture was examined under a Zeiss binocular dissecting microscope at ten diameters. It will be realized that the observations are correct only for the external and internal surface of the cranium and we have no accurate information regarding the condition of the suture deep in the substance of the skull wall. The relation between union without and within and between surface and substace must receive special attention, but we believe the condition recorded to be accurate for the surfaces and have spared no pains to this end.

In order to make possible a study of the large and unwieldy mass of data we first reduced to the comparative simplicity of a formula the conditions found in each particular cranium. The following is a typical example showing internal closure of the vault sutures:—

Internal union. Skull 649, male, White, age 22.

Sagittal 1141; Coronal $\begin{matrix}\text{R. } 230\\ \text{L. } 110\end{matrix}$; Lambdoid $\begin{matrix}\text{R. } 020\\ \text{L. } 010\end{matrix}$

This formula should be read thus:—Union of

Sagittal suture—pars bregmatica		one quarter	pars obelica	complete
pars verticis		one quarter	pars lambdica	one quarter
Coronal suture—Right side			Left side	
pars bregmatica		one half	pars bregmatica	one quarter
pars complicata		three quarters	pars complicata	one quarter
pars pterica		none	pars pterica	none

Lambdoid suture—Read for right and left in precisely the same manner as the coronal has been presented.

In the ensuing pages it will be of advantage to refer to special cases for which this formula permits simple presentation.

THE PRELIMINARY SURVEY

Having assembled the evidence in the manner just indicated we took the male White series numbering 307 specimens and plotted out on millimeter paper the degree of union for each cranium, arranging the

series in order of age. This was a very lengthy and tedious piece of work for it involved making a separate graph for each separate part of every suture for the inner and for the outer face of the skull and also for each side of the head. We then averaged the closure for each total suture and plotted right and left side graphs anew. In return for the considerable time spent upon this procedure we expected to be repaid by the convenience thus attained in examination of our data. Nor were we disappointed for, in spite of the individual difference which must be expected, we could see clearly at a glance that there is a definite trend in the progress of closure in relation to age. From these first graphic results we were able to observe roughly the commencement, progress and completion of union in every segment of each suture. It was also apparent that there are marked exceptions in certain skulls to the usual course of union and, passing rapidly from chart to chart we were enabled to note that as a rule anomaly in closure of one suture is associated with anomaly in closure of all. This segregation of anomalous skulls gave us the chance to eliminate them from the final graphs and so define more readily the age relationship of suture closure in the male sex of White Stock. Hence we were able to make a rough preliminary draft of what may be termed the modal type of suture union. The graphs also permitted us to observe that the anomalous instances fall clearly into two classes, quite orderly in their progress, of acceleration and of retardation in suture closure.

The preliminary survey of the male White Stock being completed we undertook a similar presentation of the male Negroes and of the females of each Stock. This led at once to elimination of the instances of abmodal progress in each of these series and gave us a basis for comparison of closure progress in each sex and Stock with our male Whites which we used thereafter as a standard.

Barring exceptions which must receive attention in their turn, it was now clear that there is an orderly age sequence in the progress of suture closure and that sex, Stock, cephalic index and cranial capacity affect this age sequence only in minor degree or not at all. We were forced to the conclusion that far too much has been made of the influence of each of these factors. We could also see that the time linkage is more obvious in the progress of endocranial union than upon the outside of the cranium, thus fully bearing out the helpful suggestion made by Parsons and Box. At this juncture we shall not attempt a discussion of the relative value of closure progress within and without the cranium but content ourselves with the statement that, as a result of our preliminary study,

we have adopted the closure progress of the endocranial sutures of the male White series as our standard for future work. Our initial problems were then, first, the adequate presentation of the modal type of closure progress in relation to age among the male Whites and secondly, the discussion of abmodal progress in this series.

USE OF THE MOVING AVERAGE OR TREND

Realizing the minor difficulties in problems involving age by the arbitrary subdivision of human age into units of one year we resolved to adopt the moving average covering three year intervals as our method of presentation. A few words upon this subject are therefore pertinent. All our graphs, both preliminary and final, are historigrams. That is to say they are numerical records of the degree of suture union (the variable) during successive periods of time, the unit of time being naturally one year. The degrees of union are plotted as ordinates and the age periods as abscissae. Even after the elimination of plainly abmodal instances the graphs were too large and unwieldly for publication for each graph showed precisely the state of closure for every skull in the entire series. The individual differences, though not large, were sufficient to obscure in a measure the general trend of progress. It was necessary therefore to smooth the graphs somewhat. If the total number of observations is relatively small, as must necessarily be the case in an investigation such as this, there may be grave danger of errors creeping in through too vigorous smoothing. We desired in consequence to smooth just as conservatively as we could and therefore we chose to adopt as our basis the moving average over a three year period.

If an individual give his age as say twenty-five years and we have no record of the actual date of birth we must remember that his precise age may be anywhere from twenty-four years and six months to twenty-six years all but one day, according to the individual's own method of computation. Each year of life therefore includes at the maximum eighteen months and successive "years" overlap. Further, as a result of experience, we find that mistakes of one year in either direction are not uncommon in the statements of people in ill-health or under the slightly embarrassing circumstances of being asked personal questions by nurse or doctor. I believe that with difficulties of language the individual error may in certain cases be rather more than one year although there is no means by which this can be corrected. If then we sum up the states of union for all individuals during three successive years of life as given in the records and take the average of these we shall not be far from the

actual mean value for the state of union characteristic of the second of the three years. The plotting of these three year averages will not give an entirely smooth curve for the number of instances naturally varies from year to year in a comparatively small series. We have seen no reliable method by which we could eliminate from our curves the fluctuations resulting from this fact. As I have already intimated the excessive smoothing of graphs built up from a small series is fraught with danger. Our final curves therefore are not smooth but I maintain that the advantages of retaining the irregularities outweigh the possible disadvantages in the present study. In spite of defective smoothing I shall refer to the curves as illustrating the trend of union which in point of fact they actually do.

By the nature of the method the moving average tends to indicate commencement of closure one year earlier than is actually the case and completion of union one year after the date at which all specimens show entire fusion of the suture. It is doubtful however if this is a real error for, as has been demonstrated, the precise beginning of any "year" of life is uncertain and the individual variation seems to extend over a year or two. It is true that during the progress of the work we were considerably impressed by the relatively slight variation from individual to individual and were very suspicious of this observation since it is so strangely at variance with accepted ideas. But Stevenson's work on union of epiphyses confirms us in the belief that in suture closure as in epiphysial union the current expectation of great individual variation is unnecessarily exaggerated. As will be demonstrated in the body of this work a larger acquaintance with the facts regarding suture union forces one to the conclusion that apparent individual deviations from the modal type of closure can usually be explained by accelerated or delayed union which are either phylogenetic or pathological in nature, or by inaccuracy in the age record. I am perfectly aware of the pitfalls of circular reasoning and it will be one of the most important tasks of this work to convince the reader that we have not fallen into one of these pitfalls. At the moment all we can do is to ask indulgence until the full evidence is presented. Although we have come to believe that suture closure, like epiphysial union, once it has commenced, is not normally a long drawn out affair, we are convinced, in view of the facts already presented, that it is safer to use the evidence of the moving average over three "years" regarding the commencement and completion of union than to insert the actual dates given by our present material. Except the sagittal all sutures are bilateral. The moving average for *both*

sides is therefore the basis of our final statements regarding progress of union.

GROUPING OF CRANIAL SUTURES

In discussing the cranial sutures it is convenient to have some grouping by which several related sutures can be included in a single expression. At present the recognized groupings are ill-defined and there is considerable variation according to the particular author in the exact sutures comprised in each group. The older Anatomists grouped the sagittal (and metopic), coronal and lambdoid sutures together as the sutures of the vault and this classification is convenient for our present purpose. Of late however some authors have included the squamosal suture in this group (e. g. Bolk 2). I believe this addition to be unfortunate and that it should not be continued. The older usuage will be followed in our presentation. The grouping of the three sutures of the vault (four with the metopic) is merely one of convenience and it will shortly become evident that these sutures are very widely divergent in the significance of their closure progress. As this difference in significance will be shown to be of a phylogenetic nature no further allusion need be made to it at this juncture. It is convenient classification authorized by usage but of no morphological value. Although the metopic may remain open until late in life its appearance is one of the indications of abmodality in suture union and therefore will not be considered by us in our earlier discussions.

There are certain sutures which can readily be classified together into a group which we have found to be closely related to each other in our studies of the phylogeny and growth of the cranium. These comprise in order the spheno-temporal, squamous, parieto-mastoid and occipito-mastoid sutures, a group for which Lyon has suggested the descriptive title of circum-meatal sutures. This term will be consistently used throughout our work for it shortly and aptly denotes their relation in phylogeny and growth.

The spheno-frontal and spheno-parietal sutures form a small group related from comparative and developmental points of view to both the circum-meatal sutures and to the lower coronal. It will therefore be styled the accessory group.

The spheno-occipital or basal suture has its own significance and forms a group by itself. Like the metopic it does not enter into the present study since it is already closed before the beginning of adult life. We propose then three groups of sutures with which we must deal, namely

the sutures of the vault, the circum-meatal sutures and the accessory sutures.

In this work we shall take up for consideration the modal and abmodal progress of endocranial suture union as exemplified in the male White series. In later communications we shall discuss endocranial union in its relation to sex and Stock and finally follow out its evolution in phylogeny.

LAPSED UNION

Before beginning a detailed presentation of the results of our study of suture closure it is necessary to discuss a condition by no means uncommon in the sagittal and lambdoid sutures but rarely found elsewhere upon the endocranial aspect. This condition I shall term lapsed union. It is characterized by apparent failure of union over a greater or smaller part of the suture accompanied by a heaping up of bone tissue along the edges of the unclosed part. While bone along a suture margin is still in a state of activity it presents a well defined granularity of texture very difficult to describe but none the less easily recognizable. After activity has ceased the granularity gives place to a smoothness of texture which can be likened roughly to a waxy surface. The heaped up bony margins of a suture in the condition to which I refer show this characteristic evidence of quiescence which absolutely differentiates them from the margins of a suture still in a state of active closure. The condition is not limited to Man; all mammals show the same features. There is no doubt that such sutures have been classed as patent by previous investigators and owing to this misinterpretation of the state of the suture unnecessary confusion has been injected into the age relationship of suture closure. Just why the condition develops in the sagittal and lambdoid sutures of all mammals is not yet apparent but it must nevertheless be reckoned with and discounted. A suture in this condition is unlikely to close to any greater extent. In our observations we have marked the condition by an asterisk and when we came to assemble our results we found lapsed union accounted for many of the apparent anomalies in closure of the lambdoid suture and for the greater proportion of anomalies in the sagittal. Such sutures have therefore been classed as united.

This condition of lapsed union is by no means confined to the cranial sutures. It occurs not infrequently at the junction line between epiphysis and shaft in the long bones particularly at the upper end of the tibia and the head of the femur. But by far the most frequent appear-

ance is at the line of union between the eiphysis for the iliac crest and the body of the ilium. Dr. Stevenson's work upon epiphysial union demonstrates that fusion of this epiphysis is really of considerable value as a time marker once one learns to discount the appearance of lapsed union. In his description of skeletons for the Nubian Survey Wood Jones refers to the "long delay" which the union of this epiphysis with the ilium presents especially at the hinder end (24 p. 256). Undoubtedly such cases should be classed as lapsed union.

In dealing with differentiation in the pubic bone I have shown that a condition akin to lapsed union is not uncommon in the building up of the ventral margin and upper extremity especially in White Stock (19 p. 308). It results from failure of complete ossification in the epiphysial mass on the pubis. I have also shown that the condition is present in other mammals (20 p. 414).

The peculiar features of lapsed union or lapsed ossification are always the same and are readily appreciable once their significance is understood. It would seem as though Nature grew tired sometimes of carrying on her morphological work to its completion and left the structure imperfect in appearance though not in function. The discounting of lapsed union is an important part of the interpretation of both epiphysial and suture closure.

Part I.—Male adults of White Stock

THE DETERMINATION OF MODAL PROGRESS

The 307 skulls comprised in the male White series of known age are those finally chosen as suitable for the present work since there is no reason to dispute the record of their ages and the entire skeleton is available for study. But since these skulls are spread over the life period from eighteen to eighty-four years inclusive, relatively few belong to each year and in the later part of life there are gaps of a few years without skulls. Despite this inevitable drawback the series is representative and consideration of its members inspires confidence that no essential part of the story of suture closure is defective. The collection is constantly growing and now is considerably larger than it was when the final choice of the series was made more than three years ago. Although we have been unable to include the additions in the standard series our confidence in the essential accuracy of this series is in no way impaired.

At first sight the number of skulls belonging to any particular decade

may seem perilously small upon which to build a statement of suture union so dogmatic as we are about to present but it must be remembered that the skulls belonging to the period during which union actually occurs are not to be considered as alone in presenting the evidence. They determine only the progress of union once it has begun. The uniform absence of closure in the particular suture in question in all skulls below the age of beginning union and the equally uniform occurrence of complete closure, barring occasional lapsed union, in all skulls beyond the age when completion of closure takes place, are the evidence which delimits the period of actual union and gives point to and confidence in the statements relative thereto.

In attempting to ascertain the modal progress of closure it is obvious that we should meet with exceptions to the rule. Already in our preliminary graphs in which all 307 skulls were represented the general trend of progress was sufficiently clear to us with our knowledge of the skeletons included in the series. But it was equally apparent that some skulls showed more, some less deviation from the rule. Variability in Man and particularly in the skull, prepared us for this. But the proper elimination of the variant skulls presented a very difficult problem. We had to devise some test which should not be directly related to suture closure itself, a test which should determine upon general skeletal grounds whether or not a skull ought to be retained in the first formulation of modal progress. A problem of somewhat similar character was presented in the survey of pubic symphyses which ultimately resolved themselves into three types, better marked it is true in the Negroes but nevertheless quite apparent also in the Whites. The essential feature of the pubic subdivision is the fact that certain human symphyses show their anthropoid origin more clearly than others. I have therefore spoken of the anthropoid strain of symphysis and of the regressive form (21). The latter type is more numerous than the former and therefore more characteristically human. It appeared possible that in this subdivision we had a means of separating skeletons into groups without reference to the skull and still with some reasonable hope of finding a resultant effect upon the graphs of suture union.

Between the anthropoid and regressive symphysial types there occur certain symphyses, relatively much less numerous than either of the other groups. The exact position of these it is difficult to determine. Many are certainly retrogressive examples of the anthropoid strain, nevertheless this form is properly intermediate between the other two. Now it is characteristic of the anthropoid strain that the pubic age re-

lationships fall nearer to those of the Giant Anthropoids and there is also a clear difference in age-relationship of the skeleton between human beings according as they exhibit the anthropoid strain or the regressive form of symphysis. The great mass of evidence for this assertion must await its turn for publication; at the moment we will have to accept it as a postulate. Upon this basis we first of all cut out from our series all the skulls belonging to skeletons of the anthropoid strain. Immediately the graphs of suture closure reacted in a very remarkable way for most of the skulls eliminated exhibited an unusually advanced state of closure for their age. Naturally this sweeping reduction seemed to take out some specimens which we would rather have retained but we feared to meddle with the working of the plan on which we had decided.

In my investigations upon the symphysis I demonstrated that there are some skeletons which show an accelerated type of differentiation (metamorphosis) and others in which differentiation is undoubtedly retarded. At the very beginning of the skeletal work these gave considerable worry and caused me to doubt gravely the accuracy of our age records. After a close investigation I was convinced of the essential accuracy of these records and collateral evidence assured me that there is a variable age relationship in the skeleton just as there is in other tissues and in the external features of the individual. As I have pointed out this acceleration or retardation has no relation to the type of symphysis (21). Either condition may and does occur in anthropoid strain or regressive form. Hence our next step was to eliminate all skulls belonging to skeletons which exhibit a marked anomaly of skeletal age-relationship.

For several reasons this further step was necessary. In the first place elimination based upon an anthropoid strain in the pubic symphysis affects only skeletons of the third decade. As a matter of fact it was among the skeletons of this decade that we were most in need of guidance. But for later decades we had no method of elimination upon which we felt that we could rely except the general one of skeletal age-relationship. In a very valuable and unique piece of work Bolk has shown that there are skulls which exhibit partial or complete closure of certain sutures, notably the sagittal and masto-occipital, at an early age (3, 4). In these skulls the union probably occurs entirely or for the most part before the age of seven years. We must expect to find such skulls among our series also and it is probable that, had Bolk been able to examine the entire skeletons of the children, he would have found other evidence of an unusual precocity in bony differentiation. At any rate,

upon these grounds, we felt safe in making a further elimination upon the following basis.

Bolk's remarkable findings in children's skulls lead one to suspect that there may also be a type of skull in which the closure of sutures is very long delayed or never takes place. As a result of our investigations we believe that the latter condition does occur. We therefore eliminated all skulls which we felt perfectly certain belonged to Bolk's precocious group and also those of this antithetic class.

As the result of these drastic reductions our material grew very small but at the same time remarkably uniform and harmonious in the information it now gave regarding suture closure. From this greatly restricted material we were able to discern clearly the real direction and relations of the curve of closure. The method employed is the same in principle as the one which I used to make my original estimates of age-relationship in symphysial differentiation (metamorphosis) but in that work determination was a much more prolonged and oftentimes a very discouraging process for, incidentally, so much of the basis of our skeletal work had to be laid before reliable results could be obtained for any portion of the skeleton. This basis is now built up in large measure though by no means complete but it seems probable that features of differentiation slowly and with difficulty gathered in the earlier researches will be of the greatest advantage in guiding and safeguarding the interpretation of other parts of the skeleton successively studied.

Having then obtained upon a very restricted but methodically selected material the essential data for closure of the sutures we next set about reclaiming in a guarded manner some of those specimens which we had lost. When however we finally reject a skull it must not be imagined that our guide has been simply the state of closure of the particular suture in question or yet of the sutures in general; the reason has always been a very definite one, based upon evidence in the skull or elsewhere in the skeleton of some anomaly which would give us pause, at this period of the investigation, in laying weight upon its evidence, however favorable this evidence might be to the special problem under consideration.

In reading of the method of elimination and selection of our crania it may well be wondered why we have paid no attention to the view of Ribbe that there is a significant difference in order of closure of sutures in dolicho- and brachycephalic skulls. The point will be discussed more fully later. Suffice it for the moment to state that we have found no evidence whatever of any truth in the assertion. It must also be re-

membered that Gratiolet made a distinction in order of closure between higher and lower races of mankind. What constitutes a higher and what a lower race may be open to considerable question. But it is generally agreed that the negroid races belong to the lower group and certainly it is what Gratiolet had in mind when he penned this sentiment (8). Evidence upon the subject will appear from comparison of our results on Negroes with those on Whites. Certainly there can be no differentiation between higher and lower races so far as Whites alone are concerned. We shall later have something to say upon the validity of the argument touching White idiots.

THE SAGITTAL SUTURE.
(Figs. 1 & 2)

The averages for the several parts of the sagittal suture have been gathered together into one graph from which the mean progress of the entire suture may easily be read. It is shown along with similar curves for the coronal and lambdoid sutures in Fig. 1. One should read this graph and that showing union in constituent parts of the suture (Fig. 2) at the same time. To avoid a disjointed statement we shall discuss them together. Union begins at twenty-two years or slightly earlier in the obelic part, spreading by the end of the twenty-third year to all other parts of the suture. In the obelica closure progresses rapidly to its completion at twenty-nine. In the other parts union does not gather speed until the end of the twenty-sixth year when it takes a spurt forward and has already reached the stage of closure represented by 3.5 at twenty-nine years. By thirty-one closure is almost complete in these three parts but the terminal stage is delayed until thirty-five.

The obelica then runs a course by itself and the other three parts of the suture form a harmonious group with a rather different age relationship in closure progress.

Fig. 1. naturally gives the average of all four parts and since there is marked distinction between the curve of the obelica and those of the other parts the composite curve reflects in certain degree the characters of both types. The very gradual rise of the curve just before twenty-two years is the effect of the early obelic commencement. Thereafter the composite curve follows fairly closely the curves of the three other parts which easily overpower the obelica in the final average. The composite curve is more difficult to interpret than those of the constituent parts which we might call the analytic curves: it gives only a general indication of the precise trend. But its particular value lies in the fact

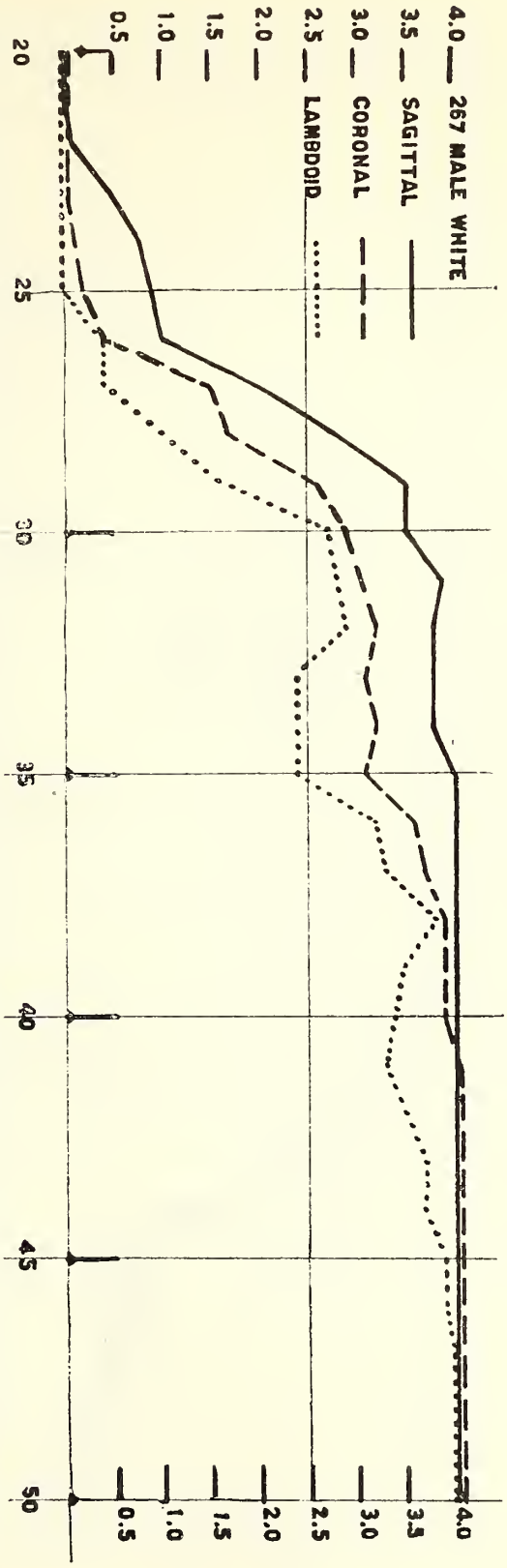

FIG. 1. Endocranial closure progress in the sutures of the vault. The relative order is shown. There is great activity between twenty-six and thirty years but lethargy before and after this period.

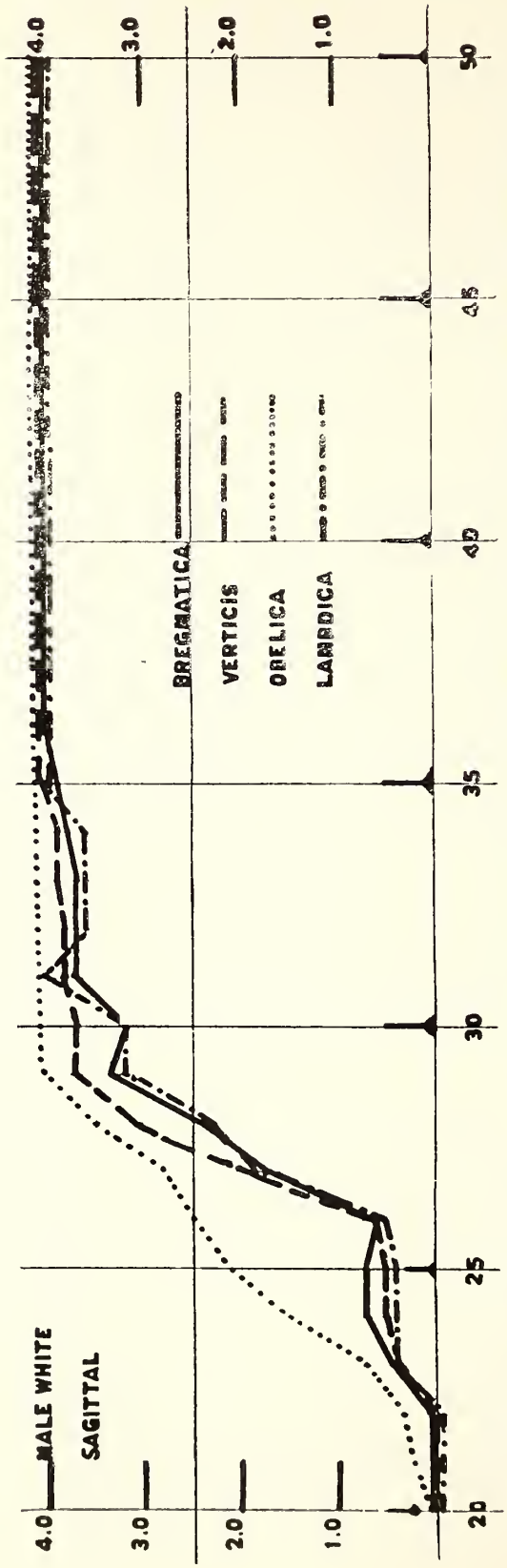

FIG. 2. Endocranial closure progress in the sagittal suture. The pars obelica has a progress of its own rather different from that exhibited in the other segments.

that it is so sensitive to initial and terminal changes. It must commence to rise as soon as any part of the suture has really begun to unite and it cannot reach completion until the last part of the suture is actually closing.

The difference between the curve of closure of the obelica and those of the remaining parts (the B. V. L. curves) is quite obvious but its significance is not entirely clear. Neither the curve of the pars verticis nor that of the lambdica at all approaches it in form. Of course one may assert that it is a primitive part of the cranium associated with the parietal foramina, but this is no satisfactory explanation. The relation of the foramina to the obelica varies greatly in different individuals. We must admit that so far no adequate reason for this peculiarity has presented itself.

The similarity in the curves for the partes bregmatica, verticis and lambdica is just as striking in its way. The pars verticis and the pars lambdica are separated by the obelica and yet the courses of union in the two run closely parallel. The initial lethargy and the terminal delay observable in all are not particularly features of the sagittal suture: they are rather a skeletal characteristic for the years during which they are exhibited. As such they will be observed again and again and must receive attention later.

The main features of closure progress in the sagittal suture can be briefly set forth in the following manner.

Male White endocranial closure commences at twenty-two years with (a) a gradual rise to 1.0 at twenty-six, (b) a sharper rise to 3.9 at thirty-one, (c) a terminal oscillatory delay with (d) complete union at thirty-five years.

No skulls of thirty-five or over, excepting instances of lapsed union, fail to show complete closure. The critical period between twenty-two and thirty-four years is represented in the collection by forty-two skulls. The tabulation of the entire series with reference to closure of the sagittal suture is the following:

Age	Period	Number of skulls	
		Retained	Rejected
18–21	pre-(a)	4	0
22–25	(a)	11	2
26–30	(b)	16	6
31–34	(c)	15	1
35–84	(d)	221	31

Total retained in series	267
Total rejected	40
Grand total	307
Percentage of discards to grand total	13.3
Percentage of discards (a)–(c) inclusive on total of this period	17.6

The value of this table lies in the ease with which one can judge from it the reliance to be given to the conclusions drawn from the survey. The total retained in the series, the total rejected, the grand total and the percentage of discards to the grand total remain the same throughout the survey of all sutures except the lambdoid. Why we have found it necessary to make changes in the survey of the lambdoid will become clear in discussion of that suture after presentation of ectocranial closure progress.

It is in the pars verticis that one finds lapsed union to occur most frequently. Here actual complete closure may be long delayed and indeed it is even possible that it is never completed in some individuals. These instances of lapsed union must not be permitted to confuse the real issue. They are comparable to the cases in which symphysial outline remains incomplete throughout life. They are readily recognized by the heaped up character of the bone along the margins of the suture. The examination of a score of skulls thirty-five years old and over will give far more confidence than pages of description in reading correctly this feature. The same condition is found especially in the lambdoid part of the lambdoid suture and occurs in other mammalian crania.

In examining critically the table of numbers of skulls used the first objection is the small number in the series before union begins in the sagittal suture. Bolk's series of 1820 juvenile skulls ends just at the age when our series commences and of this great number only 71 showed partial or complete obliteration of the sagittal suture. It is therefore clear that we have been able to plot the modal commencement correctly. The second apparent defect is the small absolute number of skulls upon which we base our determination of actual closure progress. That we have really obtained a correct record of the length of time over which the progress is spread before union is completed is evident from the fact already stated that none of the 221 skulls of over thirty-four years, barring always the instances of lapsed union, exhibits imperfect closure. These two limits of the progress of union being ascertained it cannot well be objected that our curves do not give a reasonably correct idea of the course of union during the time when it is in progress for whereas we have retained forty-two skulls we have rejected only nine. Nevertheless it is important to give the reasons for rejection of these discards. The condition of the endocranial sutures of the vault in these nine skulls can be obtained at a glance from the following table of their closure formulae. The reader will find directions for reading these formulae on page 332. They should be considered alongside the graphs of modal closure progress in the three sutures (Figs. 2, 3, 4).

			R. 230		R. 020
Age 22.	No. 649.	Sagittal 1141; Coronal	;	Lambdoid	.
			L. 110		L. 010
			R. 444		R. 344
Age 24.	No. 667.	Sagittal 3333; Coronal	;	Lambdoid	.
			L. 444		L. 342
			R. 000		R. 000
Age 26.	No. 653.	Sagittal 0000; Coronal	;	Lambdoid	.
			L. 000		L. 000
			R. 000		R. 000
	No. 490.	Sagittal 0000; Coronal	;	Lambdoid	.
			L. 000		L. 000
			R. 000		R. 000
Age 27.	No. 317.	Sagittal 0000; Coronal	;	Lambdoid	.
			L. 000		L. 000
			R. 000		R. 000
Age 28.	No. 94.	Sagittal 0042; Coronal	;	Lambdoid	.
			L. 000		L. 000
			R. 440		R. 441
Age 29.	No. 436.	Sagittal 4444; Coronal	;	Lambdoid	.
			L. 441		L. 441
			R. 000		R. 000
Age 30.	No. 238.	Sagittal 0000; Coronal	;	Lambdoid	.
			L. 000		L. 000
			R. 444		R. 000
Age 34.	No. 301.	Sagittal 1144; Coronal	;	Lambdoid	.
			L. 144		L. 000

Three of them, Nos. 649, 667 and 436 were originally thrown out as belonging to skeletons in the category of the symphysial anthropoid strain. All show plain anomalies of suture closure and, unlike certain others of the anthropoid strain, have not found their way back into the regular skull series. It is probable that we would not have dared to eliminate No. 649 on the basis of the sagittal suture alone but the condition of its coronal and lambdoid sutures renders uncertainty impossible. The other two are cases of precocious union such as Bolk found. One would not care to hazard at this stage of the investigation just when union did take place but it may be recalled that Bolk found it to occur usually by seven years.

The other six specimens deserve a somewhat fuller consideration.

No. 490 age 26, shows no endocranial closure of the vault sutures. There is obviously therefore some retardation in cranial differentiation. The symphysis is in phase IV but is an example of the intermediate type. Hence the skeleton is one in which anomalies might justly be expected.

No. 317 of age 27 required explanation in the symphysial work (19, p 316). The skeleton is that of a rachitic dwarf who showed extreme kyphosis and many anomalous conditions resulting from retarded development. It is to be expected therefore that the cranium would also show markedly retarded differentiation.

No. 94, age 28, is a case of extremely anomalous symphysis. It shows no closure whatever endocranially of the coronal and lambdoid sutures or of the bregmatic and vertex parts of the sagittal. The obelic part is completely closed and the lambdoid half closed.

Nos. 238, age 30, and 653, age 26 show no endocranial closure of these three sutures. The latter has a symphysis of the anthropoid strain, the former of the regressive type in phase VI. We have in these two specimens a condition where deficiency in cranial suture closure seems at variance with the state of the symphysis.

The same is true of No. 301, age 34, but this cranium is easily seen to be anomalous and no reference is needed to the entirely modal symphysis in phase VI. The bregmatic and vertex parts of the sagittal and the bregmatic part of the left coronal are only one-quarter closed while the other parts of sagittal and of both coronal sutures are fully united. The lambdoid suture is completely patent on both sides.

In summary of the nine discards we note that three show a condition of precocious suture closure harmonious with the state of the symphysis; three exhibit retardation of suture closure associated with retardation or anomaly of the symphysis; and three only present such divergencies in skeletal time relationship that they require further study for their elucidation.

The absolute lack of union in any of the vault sutures characteristic of several of the foregoing rejects is not so striking in the third decade as it becomes later in life. Had it not been for the facts that we have been able to examine the entire skeleton and that we possess records regarding age which we believe above suspicion we dared not have eliminated these. At the moment it is necessary to point out that if sutures are to remain patent throughout life or the greater part of it some of these anomalous skulls may be met with in such an age period as this when identification of the anomalous specimen by the skull alone would be a sheer impossibility. The determination of these skulls as unacceptable must be made upon the rest of the skeleton. This is one of the reasons for retaining in our series of skulls of known age only specimens of which the entire skeleton could be studied.

THE CORONAL SUTURE

(Figs. 1 and 3)

In dealing with the sagittal suture we had a comparatively simple problem for its position in the median sagittal plane postulates for it a relative harmony of influences impossible to assume for a bilaterally symmetrical suture like the coronal or lambdoid which bear so very different a relation to the median plane of the body. Reference to the graph of the entire suture (Fig. 1) shows that in commencement and in completion of union and therefore in the whole course of its closure the coronal suture lags somewhat behind the sagittal. This fact is well known and with this statement previous authors have generally been content. But the analytic graph (Fig. 3) showing the closure of the individual parts of the suture gives a very different conception of the progress of union in the suture. Omitting the pars obelica of the sagittal which is a law to itself, one cannot fail to be impressed with the general similarity of the curves of closure in the three other parts of the sagittal with those of the partes bregmatica and complicata of the coronal. Although these latter commence to unite rather later than the sagittal their curves of closure rapidly catch up and by twenty-nine years the degree of union is the same in both groups. Thereafter the curves run along practically parallel, final completion being somewhat delayed in the coronal. For the pars pterica the progress of union is quite different and it is obvious that it is the radically different course of this part which, when averaged in with the others, brings about the apparently simple lagging in union compared with the sagittal in the graph of the entire coronal suture.

Considering then first the partes bregmatica and complicata together we note that union commences at twenty-four years, quickly gathering speed and reaching the point indicated by 3.4 at twenty-nine. From this age onward closure proceeds more slowly and with oscillations. Complete closure, that is to say, attainment of 4.0 by the curve finally occurs at thirty-eight years.

The facts may be presented thus:—

Male White endocranial closure commences at twenty-four with

(a) a gradual rise to twenty-six, after which

(b) a steeper rise till twenty-nine years, and then

(c) a much slower and more erratic progress towards

(d) complete closure at thirty-eight years.

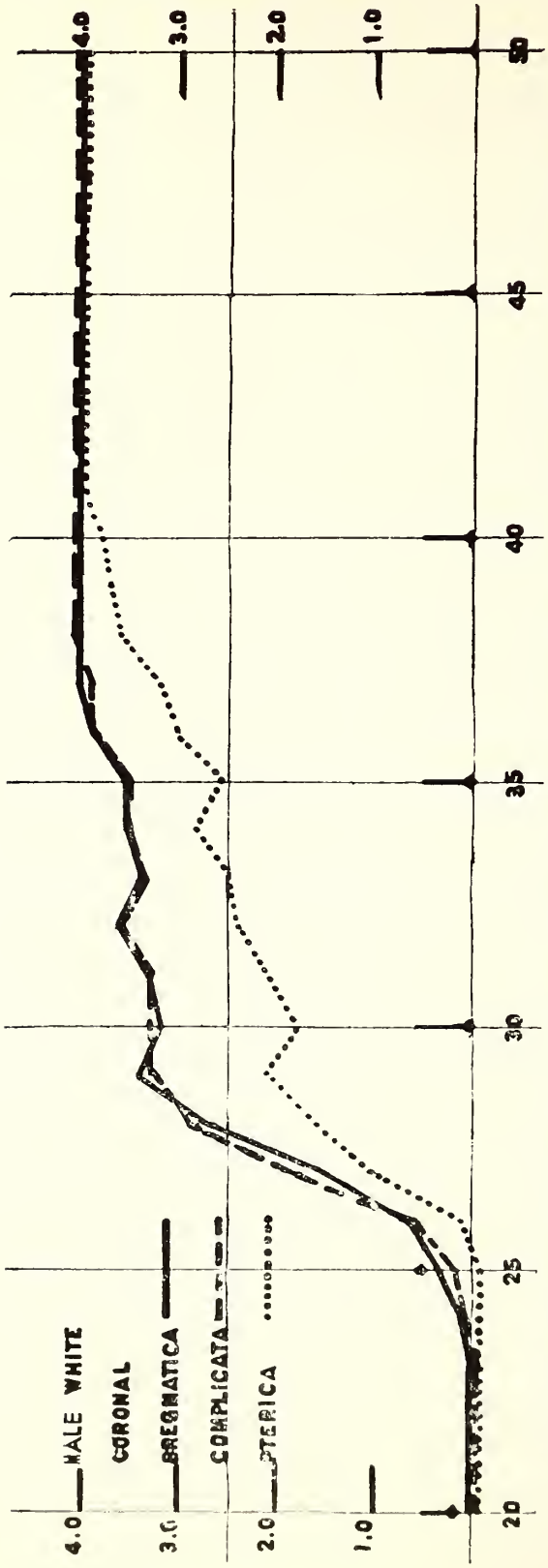

FIG. 3. Endocranial closure progress in the coronal suture. The pars pterica has a special closure progress dictated by its position in the cranium.

The table of closure is the following:—

Age	Period	Number of skulls Retained	Rejected
18–23	pre–(a)	9	1
24–28	(a)+(b)	14	5
29–37	(c)	46	7
38–84	(d)	198	27

Percentage of discards (a)–(c) inclusive on total of these periods..... 16.7

The critical period of closure (a)—(c) of the coronal suture is represented in the collection by 72 skulls of which 12 are rejected as abmodal. The extent of deviation of all discards under thirty-five years has already been shown so that we have now only to note the condition of the four rejected specimens between thirty-five and thirty-seven years.

The state of closure of the sutures in these specimens may be read at a glance from the following tabulation.

			R. 243	R. 000
Age. 35	No. 242.	Sagittal 0000; Coronal	; Lambdoid	.
			L. 244	L. 000
			R. 443	R. 100
Age 36.	No. 445.	Sagittal 4242; Coronal	; Lambdoid	
			L. 444	L. 000
			R. 021	R. 030
	No. 767.	Sagittal 0000; Coronal	; Lambdoid	.
			L. 022	L. 043
			R. 000	R. 000
Age 37.	No. 385.	Sagittal 0144; Coronal	; Lambdoid	.
			L. 033	L. 000

Compared with the usual sequence and times of closure there is sufficient irregularity in each of these to justify its exclusion.

It is at once apparent that irregularities in closure of the coronal suture, while obvious enough, are not so striking as in the sagittal and lambdoid sutures. The condition of the upper part of the suture tends to approximate to the degree of closure in the bregmatic part of the sagittal but this is only a general tendency. The trend of the coronal suture is towards delayed union rather than in the direction of precocious closure. Among his 1820 juvenile crania Bolk found premature obliteration of the coronal suture only twelve times against seventy-one instances for the sagittal.

The simplicity in pattern of the endocranial aspect of the coronal suture is very striking when the complexity of the ectocranial aspect is borne in mind. Into this question we do not propose to enter in this paper. The problem has been discussed by various authors and with their conclusions we shall deal upon another occasion. At the moment

it must be impressed upon the reader that the degree of ectocranial complexity upon which the suture is subdivided into its three constituent parts is of no significance for endocranial closure. One must dissociate these two problems for it is sufficiently apparent from our graphs that the bregmatic and complicated parts of the suture are really closely related in their endocranial closure whereas the pars pterica forms a part of another system of suture union with which we shall deal later.

The sixty modal crania comprised in the critical period of union form a singularly harmonious group. The regularity of their closure progress on the endocranial side in spite of the marked difference in ectocranial pattern between bregmatic and complicated portions (Fig. 3), and the symmetry in closure of the two sides are apparent from the preliminary analytic graphs (not published). The right side, if anything, lags a few months behind the left but it would not be wise to lay any stress upon the very slight differences in these curves. Again the bregmatic and complicated portions present almost the same pattern in their closure curves, the one being practically superposed upon the other.

These facts may be presented in the following manner:—

Pars.	Side	Closure commences at	Closure completed at
Bregmatica	Right	24	37
"	Left	24	37
Complicata	Right	24	38
"	Left	24	36

ENDOCRANIAL CLOSURE OF THE PTERIC PART OF THE CORONAL SUTURE

We have already sought to justify exclusion of the pteric part in our consideration of the major part of the coronal suture. The reasonableness of this action will become more and more apparent as the discussion proceeds. But for symmetry of presentation the facts concerning the pars pterica should be stated at once.

Closure commences at twenty-six years with a fairly sharp rise until twenty-nine when the curve begins to climb more gradually. At this age the curve stands at 2.1. Barring a few oscillations the rise after this age, though slower, is fairly steady until complete closure is attained at forty-one. Reference to the graph (Fig. 3) will render more obvious the lagging of closure in this part of the suture behind that of the complicated and bregmatic regions. Its precise significance will receive attention later.

A summary of the facts may be presented thus:—

Male White endocranial coronal closure (pteric part) commences at twenty-six with

(a) a fairly sharp rise to twenty-nine, after which

(b) a more gradual but still steady rise to

(c) complete closure at forty-one.

Age	Period	Number of skulls Retained		Number of skulls Rejected	
18–25	pre–(a)	15		2	
26–28	(a)	8	85	4	21
29–40	(b)	77		17	
41–84	(c)	167		17	

Percentage of discards (a) + (b) on total of these periods..... 19.8

The chief difference between closure of this part of the suture and closure of the other parts is the delay in commencement and in completion. It seems as though some factor begins at twenty-nine to exert a retarding action upon union throughout the entire suture and since, at this age, the pterica is already behind the other two it remains laggard in its progress. It would be exceedingly difficult to understand this delay both in commencement and in completion if the pars pterica were considered apart from closure in the cranial sutures as a whole. Later on in this presentation it will become apparent that this delay is not an accidental character but falls exactly into line with the closure progress of a suture complex other than that to which the upper part of the suture belongs.

There seems to be some evidence, not however very assuring, that union commences on the right side rather earlier than on the left but in spite of a tendency towards somewhat earlier completion on the right, this advantage constantly passes from one side to the other. We incline therefore to regard the evidence as equivocal and to consider closure progress as symmetrical.

THE LAMBDOID SUTURE

(Figs. 1 and 4)

The lambdoid, according to the graph of the entire suture, closes later than either the sagittal or coronal and this delay is appreciable throughout its course from commencement to completion. There is in this graph no indication of cephalic index. The discussion of a possible relation of shape of skull to suture closure awaits complete presentation of the data for closure in general. Gratiolet described the order of union as sagittal, lambdoid, coronal. He was opposed by Cruveilhier and

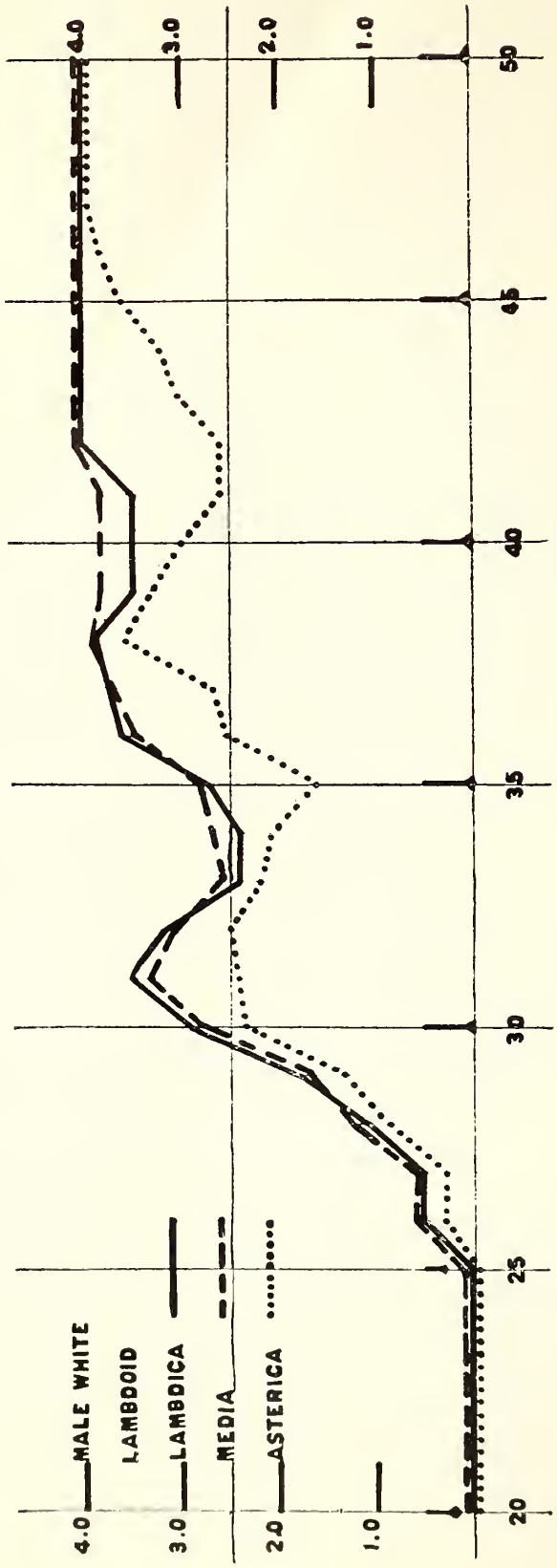

FIG. 4. Endocranial closure progress in the lambdoid suture. All parts show a period of great activity between twenty-six and thirty years. A noteworthy lethargy is exhibited after this phase.

Sappey according to whom the coronal unites before the lambdoid. Meckel and Pommerol also agreed that the coronal closes first. Ribbe objected that Pommerol's cases were too few to justify any conclusion, and himself stated the order for Parisians as sagittal, lambdoid, coronal. Ribbe also allows that the coronal is involved before the lambdoid in one out of three cases. Frédéric found the lambdoid to unite internally after the coronal, the pars media even closing before the pars lambdica. Parsons and Box believe that the lambdoid closes later than the coronal as a rule. All these observations except Frédéric's are based upon the ectocranial sutures, a problem more complex than that of the endocranial aspect. Our graphs (Fig. 1) show that there is little difference in the age relationship of union in the two sutures but that on the moving average the coronal suture does unite before the lambdoid. There are however stages where both curves reach the same point. I have previously shown how inadequate is the general graph to indicate the real course of closure and how actually misleading it may be. The real comparison should be made between the analytic graphs of the two sutures.

The actual differences in closure between the coronal and lambdoid sutures lie in certain facts. In the coronal the pars pterica has a closure progress different from that of the other parts of the suture. This, averaged in the entire suture, drags down the curve. In the lambdoid all three parts are in fairly close harmony up to thirty years. Beyond this date all are delayed and erratic, the pars asterica more than the other two (Fig. 4). The assertion that the lambdoid may close before the coronal does not hold for the endocranial aspect and it is only when the pars pterica is averaged in with the rest of the coronal that there might be any confusion regarding which suture exhibits the greater degree of closure. In coming to this conclusion one must of course discount lapsed union which occurs not infrequently in the pars lambdica. It is largely due to the failure to recognize this condition of lapsed union that previous workers have become confused in their interpretation of the order in suture closure.

At this point one must say a word regarding the fundamental difference between the investigations now being presented and those which have gone before. Until we gathered the accurately dated material in the Hamann Museum no one possessed a sufficient collection of skulls of known age to justify the interpretation of suture closure upon its age relationship. That this is possible for us is due to the fact that we have been able, in addition to the actual age records, to secure internal evidence upon other parts of the skeleton which convinces us that we are in reality dealing with a problem soluble only upon age characters.

In the researches of earlier investigators the age relationship could not be relied upon. There was therefore nothing to fall back upon except the average closure over a large number of adult crania of unknown age. This method naturally involved the concept of a closure tendency. Some sutures or certain parts of sutures show, in the mind of investigators, a greater tendency to close than others. It is easily seen that once the idea of a closure tendency is adopted the alternative concept of an age relationship recedes further in the mental picture until it becomes negligible. Add to this fundamentally erroneous idea the fact that no modal progress could be constructed upon a basis of closure tendency and also the fact that no thought of the problem of lapsed union entered the mind of previous workers and all the elements for complete confusion confront the investigator. Thus our predecessors found themselves entirely at the mercy of a meaningless closure average which must vary with every collection of crania.

From the foregoing statements it is apparent that no effective use can be made of the facts culled and deductions drawn by earlier workers. We should only confuse the reader were we to present and discuss individually the observations which others have made. Should reference to these be desired it can be readily obtained by studying thè writings of Frédéric, Ribbe and Pommerol. We shall make only infrequent allusions to these earlier efforts in succeeding pages.

In 1895 Pearson, discussing the value of the mortality curve in enabling one to localize the time and manner of selection, points out the difficulty in separating the effects of growth from those of selection upon the basis of our present knowledge (14). It is precisely this same difficulty which we are attempting to reduce by ascertaining what exactly are the effects of growth and of differentiation in the normal body. Only when this is done shall we be in a position to discuss selection adequately. Hence the fundamental importance of investigating the most readily obtainable part of the body, namely the skeleton, from the standpoint of age. Pearson further points out the salient fact that, with few exceptions, Man is the only form of life whose age at death is known. But as I have shown for the symphysis pubis, as Graves has indicated for the scapula and as Stevenson has demonstrated for epiphysial union, there is another standard by which we may gauge comparable ages throughout the mammalian class including Man. This does not involve years of life but depends upon comparable progress in skeletal growth and differentiation. With this discriminative balance ready to hand, a balance constantly becoming more delicate as we ac-

cumulate the necessary facts, biologists and anthropologists will find themselves enabled to weigh evolutionary problems which hitherto have defied all attempts at solution. The question of the cranial sutures is one of the most important pieces of evidence which can be thrown into this biological balance.

The striking feature of closure in the lambdoid suture is the long delay in the final stages of union (Fig. 4). Something of the same character appears in both the sagittal and the coronal sutures, more in the latter than in the former, but the delay in these is nothing like so great as in the lambdoid. Once again the upper two parts run a parallel course as in the coronal suture. The third or pars asterica, though following the others closely until thirty years, maintains a rather independent course thereafter. The distinction is not so marked as in the coronal suture but this is largely due to the curious terminal delay in the partes lambdica and media.

The actual facts regarding closure of the lambdic and medial segments may be thus summarized:—

Male White endocranial lambdoid closure commences at twenty-six years with

(a) a sharply maintained rise to 3.4 at thirty-one, after which it
(b) progresses slowly and irregularly to
(c) complete union at forty-two years.

Age	Period	Number of skulls	
		Retained	Rejected
18–25	pre–(a)	15	2
26–30	(a)	16	6
31–41	(b)	72	15
42–84	(c)	164	17

Percentage of discards (a)—(b) inclusive on total of these periods..... 19.3

The analytic curves (Fig. 4) show a remarkable regularity of general progress on both sides and in both parts. Commencement of closure occurs in both pars lambdoidea and pars media at twenty-six and final closure takes place uniformly at forty-two. The curious terminal delay cannot be explained at this stage of the presentation. Its elucidation will be clarified in our later work. The course of the curve is not due to a distribution of wholly patent and completely united sutures; there is tremendous variability in the extent of union in different crania during the period (b). In this respect the pars media compares well with the pars lambdoidea; it does not actually precede the lambdoidea in its progress as maintained by some previous workers.

ENDOCRANIAL CLOSURE OF THE PARS ASTERICA OF THE LAMBDOID SUTURE

As in the coronal suture we have segregated the third segment, namely the pars asterica of the lambdoid which also shows a considerable delay in progress of union compared with the rest of the suture. In brief the facts may be stated as follows:—

Male White endocranial lambdoid closure (pars asterica alone) commences at twenty-six years with

(a) an increasingly steep and fairly steady rise to 2.2 at thirty, when

(b) the curve progresses more slowly and much more erratically to

(c) complete closure at forty-seven years.

Age	Period	Number of skulls	
		Retained	Rejected
18–25	pre–(a)	15	2
26–29	(a)	10	5
30–46	(b)	109	22
47–84	(c)	133	11

Percentage of discards (a+b) on total of these periods..... 18.5

THE DISCARDS OF THE SECOND HALF OF THE LIFE SPAN

The thirteen crania up to and including the age of thirty-seven years showing an abmodal progress of suture closure have already received attention. There are still twenty-seven crania of thirty-eight years and over which do not fit in with the modal course of suture union. It is convenient to consider these together and they are therefore gathered together at the end of this section. The irregularities shown are very diverse in nature. Sometimes only a segment or two of a single suture present anomalies of closure. Sometimes the irregularity is more widely spread. In certain crania the sagittal and lambdoid sutures are at fault, sometimes the coronal and lambdoid. No crania have been withheld solely on account of lapsed union although there are such specimens in this group of abmodal crania. Instances of lapsed union are marked with an asterisk (*). A few crania showed only a slight and localized abmodality and in each this was weighed very carefully before the skull was dismissed from the typical series. In every instance it was felt that, however slight the anomaly might seem to be, accuracy required that for the present at least the cranium should be eliminated.

The formulae show that delayed union is the main cause of rejection and this delay is more marked in the lambdoid suture than in the other two. This is quite in accordance with the fact that union in the lambdoid is normally later than in the sagittal and coronal. We shall see further

on that extravagant lethargy in closure of the lambdoid is even more marked in the Negro series and results in the rejection of a much greater proportion of Negro skulls. I am convinced that much of the confusion in previous examinations of suture closure has been caused by the irregularity of lambdoid closure the explanation of which cannot be attempted at this stage.

				R. 333	R. 334
Age 38.	No. 480.	Sagittal 4444;	Coronal	; Lambdoid	.
				L. 444	L. 333
				R. 000	R. 420
	No. 581.	Sagittal 4444;	Coronal	; Lambdoid	.
				L. 000	L. 110
				R. 000	R. 000
	No. 801.	Sagittal 0242;	Coronal	; Lambdoid	.
				L. 000	L. 000
				R. 044	R. 310
Age 39.	No. 550.	Sagittal 2244;	Coronal	; Lambdoid	.
				L. 020	L. 110
				R. 430	R. 000
	No. 892.	Sagittal 4143;	Coronal	; Lambdoid	.
				L. 440	L. 000
				R. 243	R. 000
Age 40.	No. 351.	Sagittal 0010;	Coronal	; Lambdoid	.
				L. 243	L. 000
				R. 010	R. 000
	No. 619.	Sagittal 0140;	Coronal	; Lambdoid	.
				L. 020	L. 000
				R. 444	R. 000
	No. 740.	Sagittal 4444;	Coronal	; Lambdoid	.
				L. 444	L. 000
				R. 343	R. 444
	No. 772.	Sagittal 4444;	Coronal	; Lambdoid	.
				L. 343	L. 444
				R. 444	R. 330
	No. 952.	Sagittal 4444;	Coronal	; Lambdoid	.
				L. 344	L. 320
				R. 000	R. 010
Age 44.	No. 819.	Sagittal 4334;	Coronal	; Lambdoid	.
				L. 000	L. 000
				R. 444	R. 400
Age 45.	No. 320.	Sagittal 43*43*;	Coronal	; Lambdoid	.
				L. 444	L. 400
				R. 444	R. 030
	No. 395.	Sagittal 43*44;	Coronal	; Lambdoid	
				L. 444	L. 020
				R. 000	R. 3*42
	No. 689.	Sagittal 42*44;	Coronal	; Lambdoid	.
				L. 033	L. 440

				R. 444	R. 000
Age 46.	No. 188.	Sagittal 4444;	Coronal	; Lambdoid	.
				L. 444	L. 000
				R. 343	R. 0*43
	No. 352.	Sagittal 0444;	Coronal	; Lambdoid	.
				L. 444	L. 0*43
				R. 034	R. 440
Age 47.	No. 701.	Sagittal 3100;	Coronal	; Lambdoid	.
				L. 044	L. 431
				R. 000	R. 233
Age 48.	No. 213.	Sagittal 3100;	Coronal	; Lambdoid	.
				L. 100	L. 230
				R. 444	R. 200
	No. 332.	Sagittal 4444;	Coronal	; Lambdoid	.
				L. 444	L. 000
				R. 000	R. 000
Age 50.	No. 183.	Sagittal 0342;	Coronal	; Lambdoid	.
				L. 000	L. 000
				R. 040	R. 000
	No. 758.	Sagittal 0000;	Coronal	; Lambdoid	.
				L. 000	L. 000
				R. 110	R. 100
	No. 768.	Sagittal 43*44;	Coronal	; Lambdoid	.
				L. 110	L. 110
				R. 44?	R. 440
Age 51.	No. 96.	Sagittal 0444;	Coronal	; Lambdoid	.
				L. 00?	L. 443
				R. 320	R. 2*20
Age 52.	No. 890.	Sagittal 4444;	Coronal	; Lambdoid	.
				L. 320	L. 1*30
				R. 443	R. 3*40
Age 53.	No. 325.	Sagittal 4444;	Coronal	; Lambdoid	.
				L. 440	L. 0*00
				R. 443	R. 3*40
Age 55.	No. 384.	Sagittal 4443*;	Coronal	; Lambdoid	.
				L. 443	L. 3*00
				R. 3*40	R. 420
Age 56.	No. 393.	Sagittal 4444;	Coronal	; Lambdoid	.
				L. 3*40	L. 240

GENERAL OBSERVATIONS UPON CLOSURE OF THE VAULT SUTURES

In the foregoing pages we have learned the method of scrutinizing our material and the details of closure progress for each part of the three sutures of the vault. We have now to observe that upon these data there begins to take form an altogether new conception of what suture closure progress implies, a conception which permits a comparison at

once with other races and with other mammals and brings into their true perspective very important phenomena of suture union.

The general graphs (Fig. 1) indicate that for White males union as a rule begins in the order, sagittal, coronal and lambdoid. They show that the progress in closure occurs in the same order and that the curves of progress of these successive sutures never actually cross each other. Whereas union commences in the sagittal at twenty-three (twenty-two for the obelica) its beginning is delayed in the coronal until twenty-four and in the lambdoid until twenty-six. This is a fairly rapid succession compared with the ages of completed union for in the sagittal closure is perfected at thirty-five but in the coronal not until forty-one and in the lambdoid it does not occur until forty-seven years. A curious fact, and as we shall presently see, a very significant one, is that there is a period of great activity in union progress during the latter half of the third decade. The great slowing up of closure only occurs after this when the sutures are already three-quarters united.

We now turn to the analytic graphs (Figs 2, 3, 4). The third part of each suture (obelica, pterica, asterica) has a progress more or less independent of that of the remainder of the suture. The obelica has a very short period of initial delay and then climbs steadily to complete union without any terminal prolongation. The age at which union is complete, namely twenty-nine years, is the beginning of a quite significant period in the history of the cranium and of the skeleton in general. The pterica and to a less extent the asterica, though commencing to close with or soon after the remainder of the coronal and lambdoid sutures respectively and continuing with them until twenty-nine or thirty years, exhibit thereafter obvious lagging, the precise significance of which cannot at the moment be explained.

The remaining parts of each suture, at whatever age they may commence to unite, present an initial period of laggard progress but at twenty-six or twenty-seven years the curves of all shoot up steadily and reach a varying degree of union by the age of thirty years or thereabouts when slowing up of the progress again makes itself evident. One must class these sutural elements together and differentiate them from the segments already discussed. The true sutures of the vault are not the sagittal, coronal and lambdoid in their entirety but these three sutures with the pterica and asterica omitted. The obelica is a law to itself and the pars verticis in its slowing up at twenty-nine, ahead of the other elements, shows unmistakably the influence of its neighbor the obelica.

The second fact which emerges at this juncture from our study is the definiteness of suture union as a feature of the age period between twenty-six and thirty years, that is to say the last stage of skeletal growth. This period, following immediately upon the completion of union of all epiphyses, is readily recognizable in all mammalian skeletons and its real significance becomes clear in our subsequent comparative studies.

It is very interesting, though we do not yet know how important, that by the age of twenty-nine the extent of closure in all these true sutural elements of the vault has reached a little more than three-quarters of their entire extent (about 3.4, see Figs 2, 3, 4). The slowing up of the pterica and asterica, which takes place at about the same age, finds these elements united to about half their entire extent (about 2.2). It is true that the sagittal progresses a fraction more by thirty-one. This is probably because the influence bringing about the slowing up does not act suddenly but arrests further activity between the ages of twenty-nine and thirty-one, namely the period at which the skeleton as a whole becomes stationary on reaching the completely adult condition. That there is some influence at work is certain for all the sutural elements, whatever their degree of union, show arrested activity at the same age. Is it not possible that we have here evidence of the final stage in general skeletal growth with the ultimate petering out of activity and the settling down of the skeleton into a quiescent adult condition at thirty years. If we may adopt this view, and subsequent presentation of our comparative studies will show how reasonable it is, then we have a criterion for judging of comparative values in suture closure. For the present we shall consider that the later years of the third decade in Man represent a definite period in the history of sutural closure.

THE CIRCUM-MEATAL SUTURES

(Fig. 5)

The next group of sutures is one centering upon the external auditory meatus. They are, in order from before backwards, sphenotemporal inferior and superior; squamous anterior and posterior; parieto-mastoid; masto-occipital superior, middle and inferior. Abutting upon this almost circular succession of sutures are the asterica of the lambdoid and, through the spheno-parietal, the pterica of the coronal.

Before considering these sutures in detail it is well to recall that there is a period of great activity in suture closure between the twenty-sixth and thirtieth years shown in all the sutures of the vault. What-

ever the time when union first begins in the vault sutures, closure progresses only slowly until twenty-six years, and after the acceleration between twenty-six and thirty closure progress again slows down quite independently of the degree of union attained by that date.

The spheno-temporal and masto-occipital sutures, like the coronal and lambdoid, extend from the medial region of the cranium laterally, ultimately throwing themselves into the purely lateral squamous and parieto-mastoid sutures. These relations to the contour of the cranium will be found to be of the utmost significance.

No eliminations have been carried out on the basis of this group of sutures. In spite of the fact that Bolk found premature union far more common in the masto-occipital than in any other suture, namely 272 times in 1820 juvenile skulls, we have not discovered any such proportion. Bolk of course was dealing with the ectocranial sutures but even there we do not find a large proportion of premature union in the masto-occipital. So little being known concerning suture closure in this group and the actual progress illustrated by our preliminary graphs being so much less regular than in the vault sutures we have felt it advisable to carry out our eliminations upon a basis of the vault sutures alone. As a matter of fact a study of the discards shows in two only of the forty abmodal crania a real difference between the character of the masto-occipital sutures and that of the vault sutures. No. 653, of age twenty-six, exhibits a retarded condition of the vault sutures but an erratically accelerated union in the masto-occipital sutures. No. 242, of age thirty-five, presents a retarded condition of the vault and an erratically retarded appearance of the masto-occipital. The other discards show no anomaly of the circum-meatal sutures. We have however rejected them from all final graphs upon the basis of their vault sutures so as to obtain a consistent series.

The swinging course of the closure curves in these circummeatal sutures is undoubtedly due to the relative paucity of material for certain ages. With a much larger series, even with the addition of the forty rejects, the curves would have been more regular in their course.

THE MASTO-OCCIPITAL SUTURE
(Fig. 5.)

The masto-occipital suture finds a more or less natural subdivision into three parts and this subdivision we have followed. It is apparent however that, as in the case of the coronal and lambdoid sutures, the first and second parts cannot well be separated in their closure whereas

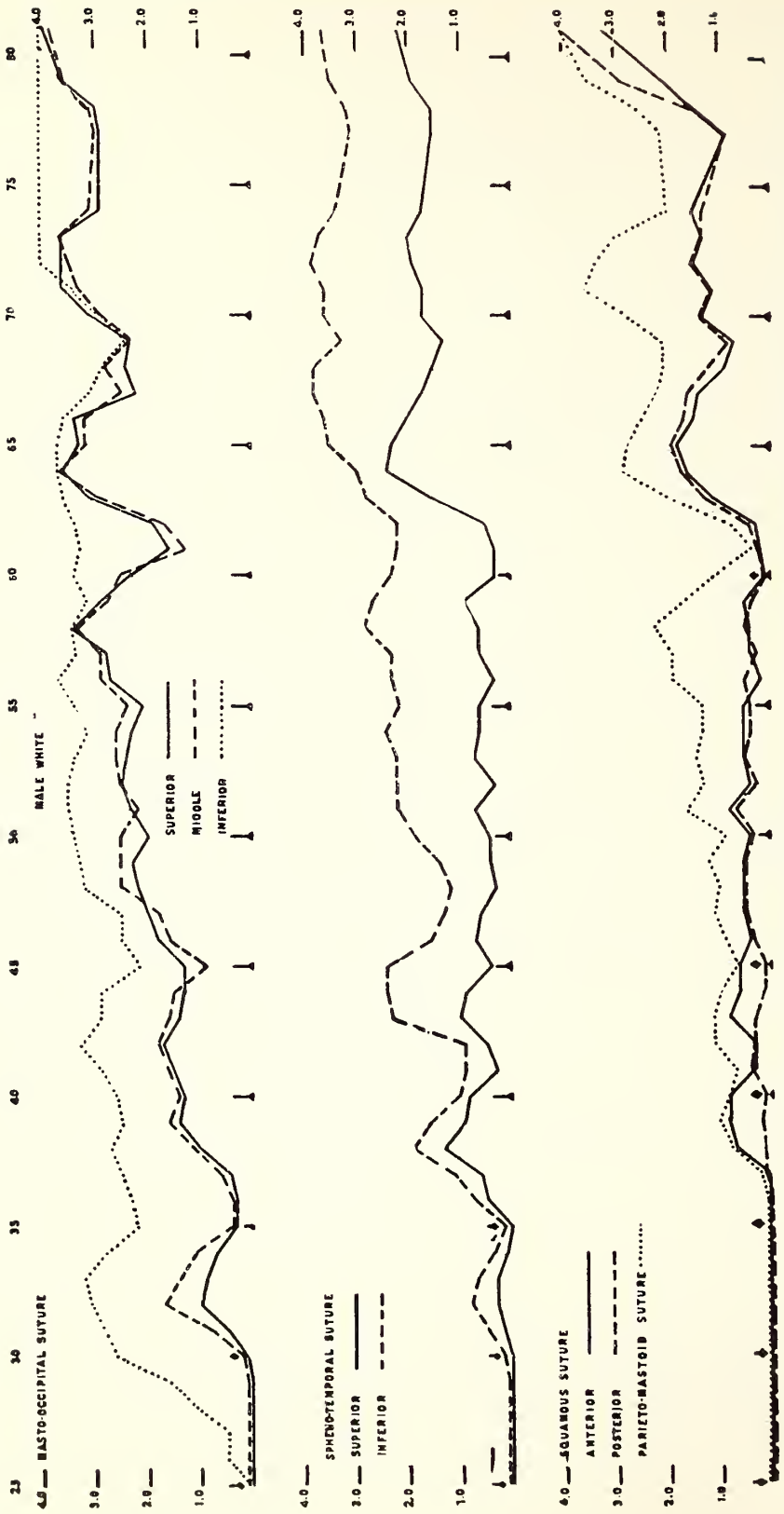

FIG. 5. Endocranial closure progress in the circum-meatal sutures. The progress in all these except the third (inferior) part of the masto-occipital suture is obviously different from the closure pattern of the vault sutures.

the third or pars inferior falls into a category by itself (Fig. 5). In our presentation of the facts we shall therefore treat the third part separately from the other two.

SUPERIOR AND MIDDLE PARTS

Closure commences in the superior and middle parts of the suture at thirty years and by thirty-two has reached an average of 1.25. At this level the curve remains fairly steady, barring oscillations, until forty-six. At this age slow progress is again made and continues until sixty-four when a second period of relative inactivity begins at about 3.5, studded with oscillatory movements of the curve, and is terminated by the climbing of the curve to 4.0 at eighty-one years. The peculiarity of this curve of closure brings to mind certain facts already ascertained in the study of other sutures. The appearance of the retarding influence at thirty-two is to be expected. Between forty-two and forty-seven years union is completed in the lambdoid suture which is of course neighbor to the masto-occipital. After sixty-four the inactivity which we find to be characteristic of other circum-meatal sutures is apparent here also. And again the final burst of energy at eighty-one is evident. I do not desire to make too much of these similarities at this point in the discussion but wish to draw the reader's attention to them in passing.

The facts regarding closure of the partes superior and media may be stated in the following manner:—

Male White endocranial masto-occipital closure commences at thirty years with

(a) a short period of activity resulting in a rise to about 1.25 at thirty-two, when the condition becomes practically stationary until forty-five.

(b) from forty-six until sixty-four there is a period of renewed activity, the curve rising erratically to 3.5, after which

(c) a second period of relative quiescence supervenes, broken by

(d) a final burst of activity at eighty-one years.

Age	Period	Number of skulls	
		Retained	Rejected
18–29	pre-(a)	25	7
30–45	(a)	106	20
46–63	(b)	94	13
64–80	(c)	39	0
81–84	(d)	3	0

Percentage of discards (a)—(c) inclusive in total of this period 13.8

THE MASTO-OCCIPITAL SUTURE (PARS INFERIOR)

Closure of the inferior part of the masto-occipital suture commences at twenty-six, four years earlier than in the remainder of the suture but at the same age as in the lambdoid. It progresses rapidly until thirty when it begins to slow down. Having reached 3.2 at thirty-three the curve remains at this level until forty-eight. After this age the curve oscillates round 3.5 until seventy-two years when complete closure is attained. There is really no great difference in this record from that of the superior and middle parts of the suture where thirty-two and forty-six years are significant dates. The final completion of union however occurs a decade earlier.

The ensuing table gives the facts briefly.

Male White endocranial masto-occipital (inferior) closure commences at twenty-six and

(a) gathers speed rapidly until thirty years when

(b) the curve of union becomes retarded about the point 3.2 until forty-nine when

(c) a period of slow progress sets in anew, resulting in a rise to 3.5, continuing at this level until seventy-two, when

(d) a final spurt of activity carries it to complete union.

Age	Period	Number of skulls	
		Retained	Rejected
18–25	pre-(a)	15	2
26–29	(a)	10	5
30–48	(b)	120	25
49–71	(c)	109	8
72–84	(b)	13	0

Percentage of discards (a)–(c) inclusive on total of this period..... 13.4

The most striking feature of union progress in the masto-occipital suture is the attempt of the third part to follow the type illustrated by the vault sutures. There is the same accelerated progress between twenty-six and thirty years and the same slowing down about that date. The upper parts of the coronal and lambdoid have reached the point 3.4 when stagnation sets in; the inferior masto-occipital has attained 3.2 when slowing takes place.

The superior and middle parts have barely commenced to close when they begin to feel the effect of the retarding influence so strongly marked in the other sutures already discussed. This influence is inhibitory but not prohibitory for union continues to progress but much more slowly. It is the almost imperceptible progress after the inhibitory influence has become effective that will, before long, be found to be the characteristic

of closure in sutures which have broken away in their time relationship from the typical mammalian form. Later on we shall be able to discuss this curious phenomenon in greater detail. It occurs in each suture of the circum-meatal group.

The final stage of closure of the inferior masto-occipital suture is very long drawn out, and that it is certainly completed at seventy-two and not earlier would be difficult to assert. Later we shall see that there is a close parallel between the final stage in this suture and the final stage of closure in the spheno-frontal which however terminates at sixty-four. The difference in time between the actual dates of complete union in these two sutures must not be allowed to obscure the very close harmony apparent in the general course of their closure curves.

THE SPHENO-TEMPORAL SUTURE
(Fig. 5.)

There is a distinct advantage in subdividing the spheno-temporal suture into superior and inferior parts for our investigation shows that the restraining influence affects in different degree the closure of the two parts (Fig. 5).

THE INFERIOR PART

Closure in the inferior part first makes its appearance at thirty years and, showing clearly the effect of inhibition, progresses very slowly until sixty-seven when the maximum union of 3.9 is attained. For practical purposes the suture is now completely united. The period between thirty and sixty-seven is naturally marked by oscillations of the curve but with a very much larger series one would be justified in expecting these oscillations to rule themselves out. The fact that closure is never quite complete is fully in harmony with the remarkably slow progress of union in this suture.

Age	Period	Number of skulls	
		Retained	Rejected
18–29	pre–(a)	25	7
30–66	(a)	205	33
67–84	(b)	37	0

Percentage of discards (a) on total of this period 12.0

SUPERIOR PART

Closure in the superior part of the spheno-temporal suture makes its earliest appearance at thirty-one, practically the same age as beginning closure in the inferior portion. But unlike the process in the latter segment progress is more definitely restrained and no further closure

takes place until the age of sixty-three when there is a sudden burst of energy which carries union up to 2.4, its maximum, at sixty-four. Beyond this age there are oscillations as there are between thirty-one and sixty-two but on the whole no further progress is made. As in other sutures it is impossible to avoid the impression that some delaying influence begins to be felt at about the age of thirty.

Age	Period	Number of skulls	
		Retained	Rejected
18–30	pre–(a)	31	8
31–62	(a)	187	32
63	(s)	7	0
64–84	(c)	42	0

Percentage of discards (a+b) on total of this period..... 11.9

We have already seen that the third part of the masto-occipital suture reproduces in the main the features of closure exhibited in the upper parts of the coronal and lambdoid sutures, whereas the superior and middle parts of the masto-occipital suture present a new type of closure progress. We now observe that the inferior part of the spheno-temporal suture reproduces the features of closure progress seen in the upper part of the masto-occipital. The superior spheno-temporal on the other hand shows a further deviation from the type common to all the vault sutures. There is practically no union at all until comparatively late in life. It is not until sixty-three years that closure becomes well marked and it is noteworthy that this age is one at which there is generally a spurt of activity recognizable clearly in other sutures also.

THE SQUAMOUS SUTURE
(Fig. 5.)

As a precautionary measure we have subdivided the squamous suture into anterior and posterior parts as was done by previous workers but our examination demonstrates that there is no real advantage to be gained from this arrangement. A glance at the graph (Fig. 5) illustrates this quite clearly. Consequently we shall not regard the subdivision except in the final analysis.

A slight degree of closure appears in (the posterior part first of) this suture at thirty-seven years but, apart from oscillations, never progresses beyond 0.5 until sixty-two when there is a renewed activity and the curve of closure rises sharply to about 1.75. There now follows a second period of stagnation until seventy-nine years when activity again appears and the maximum union is attained at eighty-one. This maximum is 4.0 or complete closure for the posterior part but only 3.2 for the anterior.

In the analysis one finds that closure begins in the anterior part on both sides at thirty-eight and is never complete. In the posterior part it commences on both sides at thirty-seven, terminating in complete union beyond eighty-one if ever.

Age	Period	Number of skulls Retained	Rejected
18–36	pre–(a)	67	12
37–61	(a)	150	28
62–64	(b)	11	0
65–78	(c)	35	0
79–80	(d)	1	0
81–84	(e)	3	0

Percentages of discards (a)–(d) inclusive on total of this period,..... 12.3

THE PARIETO-MASTOID SUTURE
(Fig. 5)

Closure in the parieto-mastoid suture follows very closely the progress of union in the squamous suture of which it may almost be considered a continuation (Fig. 5).

The first appearance of union occurs at thirty-seven years though little progress is made until the age of fifty-one. After this the curve shows greater oscillations but on the whole is somewhat speeded up in rate and complete union is attained at eighty-one as in the posterior squamous. It is possible, though our records do not definitely show it, that this suture participates in the increased activity apparent in the squamous at about sixty-two. But since the records are equivocal upon this point it is at least impossible to assert that closure steadily progresses as in the inferior spheno-temporal suture.

Age	Period	Number of skulls Retained	Rejected
18–36	pre–(a)	67	12
37–80	(a)	197	28
81–84	(b)	3	0

Percentage of discards (a) on total of this period..... ..... 12.3

GENERAL REVIEW OF CIRCUM-MEATAL CLOSURE

It is now possible to make a general survey of the features of closure progress in the circum-meatal group. It differs in all more or less markedly from the type pattern of progress as exhibited by the vault sutures. We shall refer to this condition as emancipation in various degree.

Of the several sutures the squamous exhibits emancipation in highest degree. In it there is no closure at all worth consideration until sixty-

three years when the curve runs up sharply to about 1.75. After this burst there is no further activity in the anterior part until the later spurt commencing about seventy-nine which carries the curve to 3.2 by eighty-one years. In the posterior part emancipation is not so well maintained for the last period of activity in old age brings the curve up to 4.0, namely complete union.

The parieto-mastoid suture, though following fairly closely the closure pattern of the squamous, presents features intermediate between those of the superior and inferior spheno-temporal sutures, resembling indeed the former more than the latter. As in the case of the squamous the initial start is delayed till the end of the fourth decade but more progress is made after fifty-one years. From this time on a slightly increased rate is maintained which ultimately results in complete union. Hence in later life the progress of the parieto-mastoid suture is more like that of the inferior spheno-temporal suture. In middle life its closure pattern resembles that of the superior spheno-temporal and the squamous.

The superior spheno-temporal suture gets a rather earlier start than the squamous though it is doubtful if this should receive much weight since it is so badly maintained. Once it has started the features of the curve are very like those of the squamous and it participates in the renewed activity of the earlier years of the seventh decade.

The inferior spheno-temporal and the superior and middle parts of the masto-occipital run almost parallel courses which have been sufficiently indicated. The inferior masto-occipital shows the least degree of emancipation from the type pattern of the vault sutures.

Now, if the curves for the pterica of the coronal, the asterica of the lambdoid and the inferior masto-occipital be compared it will be seen that they form a graded sequence in emancipation from the true vault suture closure pattern. We may then establish a sequence in emancipation showing the lowest grade in the coronal pterica and the highest in the anterior squamous. The order of emancipation is the following:—

Coronal pterica; lambdoid asterica; inferior masto-occipital; superior and middle masto-occipital and inferior spheno-temporal; parieto-mastoid; superior spheno-temporal; posterior squamous; anterior squamous.

SIGNIFICANCE OF THE DISCARDS

It has already been stated that the discards have been rejected upon the basis of their vault suture progress alone. That there should be but two crania which could be fairly discarded upon the basis of progress in

union of the circum-meatal sutures is an arresting fact and, taken in conjunction with the results of our observations upon the vault, a problem worthy of further study. I have mentioned that, in all sutures the retardation of closure progress commencing about the age of thirty years is an inhibition rather than a prohibition of further closure. There are however certain crania in which further union seems to be permanently inhibited. To this we must return later but its occasional occurrence is a natural extreme degree of the variability induced by the retarding influence.

TABLE I. TABLE OF DISCARDS—MALE WHITE

1	2	3	4	5	6	7	8	9
Age period	Total	Discards		Remaining in series		Percentage of discards		
(Decade)		Inclusive of all (A)	Retarded only (B)	Total —col. 3 (A)	Total —col. 4 (B)	Col. 3 to col. 2	Col. 4 to col. 2	Col. 4 to col. 6
10–19 (2nd)	2	0	0	2	2			
20–29 (3rd)	30	7	4	23	26	23.3	13.3	15.4
30–39 (4th)	67	11	9	56	58	16.3	13.4	15.5
40–49 (5th)	81	14	10	67	71	17.3	12.3	14.1
50–59 (6th)	61	8	7	53	54	14.7	11.5	13 0
60–69 (7th)	44	0	0	44	44			
70–79 (8th)	19	0	0	19	19			
80–89 (9th)	3	0	0	3	3			
Totals.....	307	40	30	267	277	13.3	9.8	10.8

If we refer to the table of discards (Table I) we observe that there is no plain relation between the number of discards and successive age periods (column 7). But if the crania showing accelerated, locally anomalous and erratic closure be discounted, leaving only those discards which exhibit pure retardation, then we find a very significant relationship of discards both to the total number of each age period (column 8) and to the number of modal crania left in each age period (column 9). The discards are all eliminated upon the basis of their vault sutures and the vault sutures all attain complete union during the fourth and fifth decades. During the third and fourth decades the percentage of discards remains stationary but diminishes in the fifth and sixth decades and there are no retarded examples found beyond the latter. We do not here propose to discuss permanently inhibited suture union which we term for convenience the asterisked suture; we refer only to pure retardation.

We have seen by the graphs that retardation setting in about thirty years is merely a slowing down influence and does not result in any permanent prohibition of union. We now see from this table that the

discards, eliminated because of retardation in vault closure, exhibit merely delayed union and that eventually their vault sutures would probably all close. We are then observing the effect of an influence which tends to make its presence felt throughout adult life in Man, affects some sutures (the circum-meatal group) more than others (the vault group), and has a specially marked effect appearing quite suddenly at about thirty years. Granting that we are compelled by the facts to concede the existence of a retarding influence, we may expect that certain sutures will exhibit retardation more than others. This has already been demonstrated (page 370). Concerning the cause for the existence of the retarding influence it is rather early in the discussion to build any hypothesis but I consider the retarding influence related to local evolutionary development of the cerebrum.

Turning now to the several lists of discards it becomes evident that retardation is much more marked in the lambdoid than in either of the other vault sutures. As a rule also it is the lower part of the suture which shows retardation most clearly. This means of course that in certain crania the lambdoid suture presents a closure progress resembling more or less closely that of the circum-meatal group. We note this tendency even in the modal course of the lambdoid graphs (Fig. 4). It is by no means to be inferred that the sequence of emancipation in the circum-meatal group is rigidly adhered to, or that I desire to emphasize the several degrees of emancipation. Rather I would explain that there are groupings of sutures which present closure patterns intermediate between the extreme types illustrated by the true vault sutures on the one hand and the squamous on the other. If we start with the squamous itself and follow the suture line backward we are able to note progressively less degrees of emancipation as we trace the parieto-mastoid and then either the lambdoid upward to the lambda or the masto-occipital downward, which latter sutures may be considered as the inverted mirror image each of the other.

It is probably this varying emancipation of the lambdoid suture which has produced confusion in the statements of previous authors regarding early or late closure of the lambdoid suture compared with union of the coronal. It is probably also responsible for the fairly wide-spread belief that there is some relation between the relative date of lambdoid closure and the cephalic index.

THE ACCESSORY SUTURES
(Fig. 6.)

We now pass to the consideration of two sutures which in view of their position, scarcely belong to the circum-meatal group, and more cer-

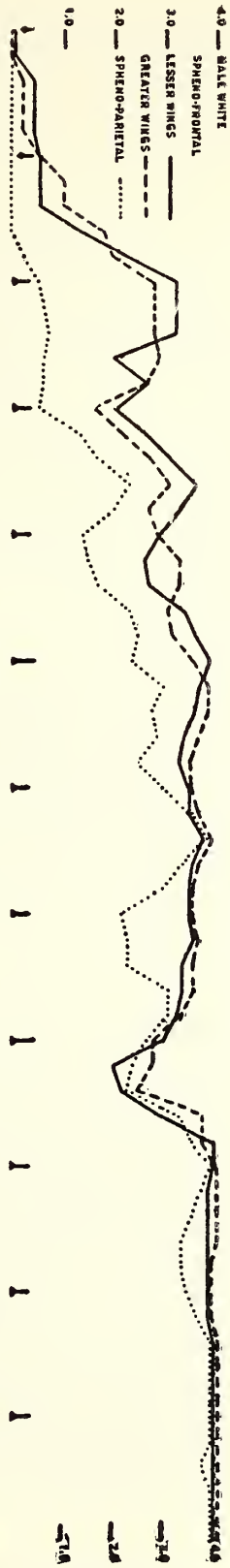

FIG. 6. Endocranial closure progress in the accessory sutures. The pattern of sphenofrontal closure simulates that of the vault sutures whereas that of sphenoparietal closure resembles more closely the pattern of circum-meatal closure.

tainly, by their closure pattern, form no part of the vault series. These are the spheno-parietal and spheno-frontal sutures. As the story of their closure is unravelled it becomes clear that they lie upon the threshold of emancipation and form, as it were, a link between the true vault sutures and the circum-meatal group.

THE SPHENO-PARIETAL SUTURE
(Fig. 6.)

Closure in this suture commences at twenty-nine and, encountering the delaying influence almost at once, progresses quite gradually and with many oscillations until forty-six when the graph has reached the level of 3.0. After this the course of the graph (Fig. 6), is very irregular although there is some slight progress until sixty-four. At sixty-five complete closure is attained as in the spheno-frontal suture. It is true that the graph shows a sagging of the curve beyond this point but I am inclined to regard this as spurious and simply resulting from paucity of material.

The facts briefly are these:—

Closure commences at twenty-nine years and is almost immediately slowed down so that there is a

(a) slow progress to forty-six when the curve stands at 3.0, then
(b) a period of considerable oscillation with little progress to sixty-four,
(c) complete union occurring at sixty-five.

Age	Period	Number of skulls Retained	Rejected
18–28	pre–(a)	23	6
29–45	(a)	108	21
46–64	(b)	97	13
65–84	(c)	39	0

Percentage of discards (a+b) to total of this period..... 14.2

The type of closure of this suture corresponds very closely with those exhibited by the inferior spheno-temporal and by the superior and middle parts of the masto-occipital. This is the more striking since closure of the spheno-frontal and of the inferior part of the masto-occipital is found to be so harmonious. Closure in the spheno-parietal begins indeed one year earlier than in the upper masto-occipital but in both there are distinct periods between thirty and forty-five, and from forty-six to sixty-four. Both periods are characterized by slow progress, it may be very slow, and the completion of union in the spheno-parietal is balanced by the attainment of the maximum closure in the masto-occipital.

We see therefore lesser stages of emancipation in the several sutures progressively more remote from the focus of emancipation, namely the anterior squamous.

THE SPHENO-FRONTAL SUTURE
(Fig. 6.)

In considering the spheno-frontal suture one cannot help the suggestion that here we have a suture which, like the sagittal and the inferior masto-occipital has only a remote and modified relation to phenomena of cerebral development. One is therefore already prepared to find a graph of the moving average different from those of the other sutures which carry its line backwards.

In the first place the graph (Fig. 6), shows a close parallel between the curves of the two parts so that it becomes unnecessary to treat them separately.

In both parts closure commences at twenty-two and, as usual, makes rather slow progress during the next years. In the region of the greater wings at twenty-five and in that of the lesser wings at twenty-seven the rate of union rapidly increases and by thirty years the curve centers at about 3.0. It is somewhat striking that the speeding up process begins for this suture, as for all the others, about the age of twenty-six. This speeding up is obviously a general characteristic of suture closure and unrelated to particular location. After thirty years there is a long period of oscillation during which union on the whole makes no progress. This ends at sixty-four. At sixty-four the suture of the lesser wings, and at sixty-five that for the greater wings is completely closed.

These facts may be briefly stated in the following manner:—

Closure commences at twenty-two with

(a) a gradual rise to 0.7 at twenty-six, followed by

(b) a steeper progress to 3.0 at thirty, when there commences

(c) a period of oscillation with no further union ending at sixty-four, and resulting in

(d) complete closure at or about sixty-five.

Age	Period	Number of skulls Retained	Rejected
18–21	pre–(a)	4	0
22–25	(a)	11	2
26–29	(b)	10	5
30–64	(c)	203	33
65–84	(d)	39	0

Percentage of discards (a)–(c) inclusive to total of this period..... 15.1

Comparison of the graphs of this suture and of the inferior masto-occipital shows a very striking likeness. It is true that closure commences about four years earlier in this suture than in the pars inferior of the masto-occipital but both exhibit the speeding up process about twenty-six, the slowing down at thirty years and the long ensuing period of oscillations without further progress. The similarity only breaks down in old age because of the unexpected, and probably unwarrantable, dip of the graph for the pars inferior in the sixties.

Comparison with the graph of the lambdoid asterica also shows striking similarities. Except for the early start of union in the spheno-frontal, a start which is not at all maintained, union follows an almost parallel course in both these sutures. Indeed the course of closure in the spheno-frontal may more properly be considered intermediate between those of the superior and middle lambdoid on the one hand and the pars asterica on the other. This similarity brings into one group the spheno-frontal, the lambdoid and the inferior masto-occipital, three sutures on the frontiers of the zone of emancipation, the center of which is in the anterior squamous. When one realizes this close similarity the early commencement of union in the spheno-frontal becomes all the more striking. For here on the very edge of emancipatory influence is a suture which begins to close as early as the sagittal, a suture undoubtedly presenting an ancestral stage in the time relationship of its commencing union. In further studies it will be our task to follow the clues given in age relationship of suture closure regarding the ancestral condition of the human closure pattern.

THE PERIODIC CHARACTER OF SUTURE UNION

In studies upon the skeleton, growth and differentiation should be sharply distinguished. The amount of increase in dimensions of a long bone is one thing and the actual union of its epiphyses is another. The two have been regarded as closely related aspects of a single problem. In certain cases of a pathological nature they are completely dissociated. I think it safer not to link them inseparably in normal anatomy until they have been definitely shown to justify this treatment. Actual increase in dimension may not be taking place uniformly throughout the period before actual epiphysical union though there may be, and probably are, continuous alterations in adjustment between epiphysis and diaphysis. This latter is a problem of differentiation, not of growth. Cranial suture closure has probably no very definite relation to cranial growth. Certainly the cranium is not growing in its various parts

throughout the life period until union of all the sutures takes place. Suture union is a problem of differentiation rather than of growth.

Having observed the picture of progressive closure as it presents itself in the several sutures we are now in a position to note that the nature of this progress differs greatly in different areas of the cranium. The course of closure in the vault sutures is not at all the same thing as the course in the squamous suture and between these two extremes there are intermediate types of progress related definitely to the particular area of the cranium in which the suture finds itself.

The age relationship in detailed progress of union varies with the suture but in all sutures there is a periodicity of union. We have observed marked activity of progress between the ages of twenty-six and thirty years and sudden diminution of activity immediately thereafter. No matter what stage of union is reached, the suture does not continue to unite so rapidly after thirty years as it did before. But although the period of extreme activity, one might say the typical period of suture union, occurs from twenty-six to thirty, there seem to be subsidiary periods when activity receives a further impetus, and these periods can be traced even into old age. In certain graphs it may indeed be doubted that any impetus can be discerned. Nevertheless in general the curves of union do show periodicity and spurts of increased progress tend to alternate with periods of relative quiescence. I have already demonstrated a similar periodicity in the differentiation (metamorphosis) of the pubic bone (19, 22) after adult life is reached, exhibiting a similar rather poorly defined age relationship. These are the periods of quiescence and secondary changes which are not as yet fully worked out for they do not present the clear cut age relationship characteristic of the earlier phases of pubic differentiation. It is as though Nature grew somewhat tired of regulating precisely the order and date of differentiation and gave more latitude to the individual after middle age. This relatively ill-defined age relationship is characteristic of all features of differentiation during the second half of the life span so far studied in this laboratory. It is only in later communications that I shall be able to lay stress upon this periodicity in differentiation to the extent which it deserves for I recognize that much more evidence from various parts of the skeleton must be presented before its existence and significance can be made clear.

In the present study it is however plain that cranial sutures tend to close with marked vigor between twenty-six and thirty years and there are varying degrees of emancipation from this regulation apparent

in certain sutures. The squamous suture shows emancipation in highest degree and the sutures in the vicinity of the squamous exhibit emancipation apparently depending upon the varying relation of their site to the squamous. The spheno-frontal and inferior masto-occipital sutures therefore present curves of closure progress most closely simulating those of the true vault sutures.

In order that the reader may clearly appreciate the complex age relationship and periodicity of suture closure I have drawn up a table giving briefly the outstanding facts (Table II).

TABLE II—CRANIAL SUTURES—MALE WHITE ENDOCRANIAL CLOSURE

Suture	Commencement and course		Termination (or peak)	
Sagittal	22	slow to 26	35	slows at 31 at 3.9
Sphenofrontal lesser w.	22		64	slows at 30 at 3.0 final burst of activity
Sphenofrontal greater w.	22		65	slows at 30 at 3.0 final burst of activity
Coronal 1 and 2	24		38	slows at 29 at 3.4
Coronal 3	26	rapid to ca 30	41	slows at 29 at 2.1
Lambdoid 1 and 2	26		42	slows at 31 at 3.4
Lambdoid 3	26		47	slows at 30 at 2.2
Masto-occipital 3	26		72	32–48 at 3.2 slow progress thereafter
Sphenoparietal	29	slow at once	65	29–46 at 30. slow progress thereafter
Sphenotemporal 2	30		67 at 3.9	gradual progress
Sphenotemporal 1	31		64 at 2.4	31–62 at 0.5 burst of activity at 63
Masto-occipital 1 and 2	30		81	32–45 at 1.25 activity between 46 and 64 final burst of activity
Parietomastoid	37		81	almost inactive till 50 slow progress thereafter
Squamous posterior	37	almost inactive till 62	81	burst of activity at 63 burst of activity at 79
Squamous anterior	37		81 at 3.2	burst of activity at 63 burst of activity at 79

The sagittal and spheno-frontal sutures commence to unite at twenty-two years. There is slow progress until twenty-six when the period of rapid union sets in and lasts till about thirty years. By this time the sagittal is almost completely united and its terminal inhibition is of no real consequence. The spheno-frontal however is only three-quarters united at this age and falling under the restraining influence, its union remains practically stationary until the final burst of activity in the early sixties.

The upper part of the coronal suture, starting to unite two years later than the sagittal, follows a similar course but its terminal inhibition is not nearly so prolonged as that of the spheno-frontal for it is remote from the zone of maximum emancipation (squamous).

The pteric part of the coronal, the entire lambdoid and the third part of the masto-occipital all commence to unite at twenty-six and progress as far as thirty years is rapid. The pterica and asterica have united only about one-half their extent by thirty but the upper lambdoid and the third masto-occipital, being further removed from the zone of maximum emancipation, are three-quarters united. At thirty years retardation sets in and complete union attained at ages varying from forty-one to seventy-two.

APPLICABILITY TO INDIVIDUAL CASES

In a study of this kind it is natural for the reader to inquire what value it has for the identification of age in individual cases. Indeed when we first commenced the work we had in mind the utilization of suture closure, along with other features of skeletal differentiation, in estimation of the actual age of the person. In order to show what may be attained by the method I have taken thirty skulls at random and worked out the suture age for comparison with the known age. The results of this investigation are given in Table III. While the average computed age very closely approximates the average real age, as might be expected, the results in individual cases leave much to be desired for the average deviation is rather more than six years. I have not claimed greater accuracy than this for age estimation based upon any single segment of the skeleton and when one considers the individual variability in suture closure progress this result is far from discouraging. But it cannot be denied that so far our work does not justify the uncontrolled use of suture closure in estimation of age. Frédéric (7) concluded that it is not possible to gauge the age of any particular individual closer than within one decade and after all we have not greatly bettered this result.

Our results are of distinct value however when taken in conjunction with indications given by other parts of the skeleton.

The real value of this work lies in the light thrown by it upon the nature of suture closure. I have already dwelt upon this aspect of our results and it is only after presentation of our complete investigations,

TABLE III. ESTIMATION OF AGE BY ENDOCRANIAL CLOSURE

Skull	Suture age circa.	Actual age	Dev.	Skull	Suture age circa.	Actual age	Dev.
94	25	28	—3	618	30	30	
156	40	45	—5	649	27	22	+5
185	40	40		654	65	42	+23
267	25	25		671	35	33	+2
301	35	34	+1	678	40	38	+2
328	55	38	+17	708	45	32	+13
354	65	48	+17	711	43	47	—4
396	41	60	—19	772	37	40	—3
429	35	40	—5	786	43	45	—2
431	45	40	+5	794	33	32	+1
445	30	36	—6	799	35	36	—1
499	43	55	—12	823	30	33	—3
504	35	37	—2	828	58	68	—10
507	35	49	—14	876	43	ca 40	+3
617	37	32	+5	896	55	53	+2

Average of thirty. Suture age 40.2 years. Actual age 39.9 years. Dev. 6.2

which comprise Negro Stock and comparative mammalian anatomy, that we shall be able to demonstrate satisfactorily the full truth concerning suture closure. At the moment I can merely reiterate my belief, expressed in several places above, that there is a mammalian type of order and progress in suture closure from which various degrees of emancipation are exhibited in higher Primates. In Man the greatest degree of emancipation is attained. It is too early as yet to speculate upon the very interesting question whether the amount of individual variation should be construed as an indication of inadequacy in this emancipation, or whether the type of skull may have some real relation to the precise individual character of suture closure progress. Work along this line has been in prosecution for many months but so far I am not ready to report.

SUMMARY

The numbers of paragraphs in this summary refer to the numbers of corresponding subject headings in the table of contents.

1. So little work has hitherto been done upon endocranial suture

closure in material of definitely known age that it is necessary to make an absolutely fresh start. The previous work of Parsons and Box is the most helpful and suggestive.

2. The present survey included 307 male White skulls of age known either precisely or within a year or two. But since the making of the survey in 1921–22 we have had opportunity to test its principles upon a considerably increased collection and we find the principles are confirmed.

3. By a detailed preliminary survey we were able to identify a definite trend of progress in suture closure. There is obviously considerable individual variation but the mean values of the trend are closely similar in series restricted to one Sex and Stock. Abmodal examples must naturally be eliminated.

4. A three-yearly moving average or trend illustrates in a practical visual manner the progress of suture closure and its relation to age. It is unnecessary and indeed it would seem unwise, at least at the present stage, to smooth the graphs too much.

5. Endocranial closure progress compels us to adopt a new method of grouping the sutures. The group of vault sutures includes sagittal (and metopic), coronal and lambdoid with some reservations on the partes pterica and asterica of the two last. It does not include the squamous suture. A second group presenting an entirely different age-relationship in closure progress has been named by us the circum-meatal group. This includes the spheno-temporal, squamous, parieto-mastoid and occipito-mastoid sutures. The third and last group, styled the accessory group, comprises spheno-frontal and spheno-parietal sutures.

6. Frequently in the sagittal and lambdoid, rarely in other locations also, there occurs an apparent failure of union with heaped up bone tissue along the margins of the unclosed part. We have described it under the heading of lapsed union. This must be clearly distinguished from union which, though in fact incomplete, would normally have been completed later.

7. The elimination of specimens exhibiting what is known or suspected to be abmodal progress is an important step.

8. The sagittal suture commences to unite at twenty-two years and is practically completely closed at thirty-one, progress becoming much more rapid at twenty-six.

9. The coronal suture begins to close at twenty-four years. From twenty-six to twenty-nine there is rapid progress and thereafter union

spreads very slowly, completion being attained at thirty-eight. The pteric part is delayed in its commencement until twenty-six and in its completion until forty-one but it shows the same speeding up from twenty-six to twenty-nine.

10. The lambdoid suture begins to close at twenty-six and though progress is rapid until twenty-nine it is fitful thereafter until complete at forty-two. The asteric part, though commencing at the same age does not complete its union until forty-seven.

11. Crania presenting abmodality in suture closure are not infrequent. Sometimes the irregularity is localized to a single suture, or even to the segment of a suture. All such crania in this series have been rejected. The main cause of rejection is delayed union and this delay is more frequently met with in the lambdoid suture than in the sagittal or coronal.

12. Endocranial closure of vault sutures in male White crania commences and terminates in the order, sagittal, coronal, lambdoid. The discrepancy in age is greater for completion of union than for commencement. The age period of twenty-six to thirty years is the special period of suture closure. At whatever stage union may have progressed there is a significant slowing up once this period is passed.

13. The circum-meatal group of sutures presents a closure pattern quite different from that of the vault sutures. This group comprises the spheno-temporal, squamous, parieto-mastoid and masto-occipital suture.

14. The masto-occipital suture commences to close just about the thirty-year period when lethargy in progress is setting in. A second period of activity is shown in the fifties and a third and final burst about eighty years. The inferior part however commences at twenty-six, slows down at thirty, gathers speed again in the fifties and finally reaches complete union in the seventies.

15. The inferior part of the spheno-temporal suture shows a closure pattern similar to that of the major part of the masto-occipital but complete union is rare. The superior part is even more restrained in its degree of closure.

16. In the squamous suture closure does not begin until the late thirties and is rarely over complete, at least in the anterior part.

17. Closure in the parieto-mastoid suture presents a pattern similar to that of the squamous suture but complete union is attained as in the posterior squamous, at eighty or over.

18. The circum-meatal group clearly shows various degrees of emancipation from the closure pattern typified by the vault sutures. The

greatest degree of emancipation occurs in the anterior squamous suture.

19. The retarding influence which makes its appearance in suture closure at thirty years affects some sutures more than others but certain crania seem to exhibit retardation in more marked degree than others. In these sequence of union may remain unaffected.

20. The spheno-parietal and spheno-frontal sutures form a link, as it were, between the vault group and the circum-meatal group. We style them the accessory sutures.

21. In the spheno-parietal suture closure, commencing at twenty-nine years, is almost immediately retarded but shows a second burst of activity in the fifties carrying union to completion in the early sixties.

22. Union in the spheno-frontal suture begins at twenty-two, shows the usual activity from twenty-six to thirty years, after which oscillation and slow progress supervene until complete closure at about sixty-five.

23. Suture closure exhibits a definite periodicity, the most extreme activity occurring between twenty-six and thirty years. Subsidiary periods of activity occur in the fifties and the late seventies.

24. The individual variability in progress of suture union makes it unwise to depend too much upon the stage as an age marker, valuable as the indications may be when linked up with other features. The average progress of a large number of crania however shows that there is a definite pattern in suture union. The most primitive form is still represented in the sagittal suture and the greatest degree of emancipation from that primitive form is exhibited in the squamous suture.

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CRANIAL SUTURE CLOSURE

ITS PROGRESS AND AGE RELATIONSHIP

Part II.—Ectocranial Closure in Adult Males of White Stock

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INTRODUCTION

In a recent paper we have announced our intention of making a complete study of cranial suture closure (6). We have already presented the results of our investigation of endocranial closure in White males and because of their relative constancy, we have proposed these results as a standard of comparison for our work upon ectocranial closure and Negro sutures. Our present task is to set forth as briefly as possible our findings on the subject of ectocranial closure in male White Stock.

It is only after discussing ectocranial closure that one can profitably compare our results with those of others for until now there has been little opportunity for systematic study of the inner surface of the cranium. Indeed in the work of most former writers one cannot be sure what statements refer to endocranial closure and what are the result of ectocranial study: many authors have simply contented themselves by saying that endocranial closure occurs somewhat earlier than and follows practically the same pattern as ectocranial closure.

Our investigation has disclosed the following broad facts.

1. There is no tendency on the part of the sutures to commence to close earlier on either aspect of the cranium. Inspection of our graphs

demonstrates that when closure begins it is equally evident both ectocranially and endocranially.

2. Ectocranial closure exhibits a slower and more variable progress and there is less evidence of periodic activity than endocranially.

3. Ectocranial closure on the whole is never so complete as endocranial union.

MATERIAL AND METHOD

It may be recalled that out of our large collection of skulls we chose for the study of endocranial suture closure 307 male White skulls, our two criteria being the existence of the entire skeleton and definite knowledge of the age. Of these 307 skulls 40 were rejected because of obvious anomalies in suture closure or for other sufficient reasons. The remaining 267 skulls form the basis alike of our investigations on endocranial closure and on ectocranial union, but for our study of ectocranial closure we have not hesitated to add more recent accessions to our collection since a greater number adds appreciable weight to the results.

There is no need to specify in detail the method of examination: that has been sufficiently described (6). It will be enough to state that the method is in all respects the same as that adopted for the endocranial sutures and once again the graphs are based upon a three-yearly moving average or trend. The trend is a specially sensitive indicator for the commencement of closure: this is noteworthy in the present work for the graphs show what we shall term a spurious commencement in the closure of many sutures. It is the result apparently of an effort of Nature, not well sustained, to start union first on the ectocranial surface.

Lapsed union has been described in our earlier paper. It presents certain well marked features which pick it out without difficulty wherever it occurs. Endocranially it is frequent in the lambdoid suture, especially in the pars lambdica where its occurrence has led previous observers into the erroneous view that closure is incomplete, and in the sagittal suture. Ectocranially it is characteristic of all sutures. It must not be confused with the lethargy in closure which develops at the termination of the period of election, namely shortly after thirty. The restraining influence responsible for lethargic closure is an inhibition but whatever brings about lapsed union is of the nature of a prohibition.

We shall not dwell upon the problem of the discards in this paper. No further discards have occurred and the method of rejection has already been fully described.

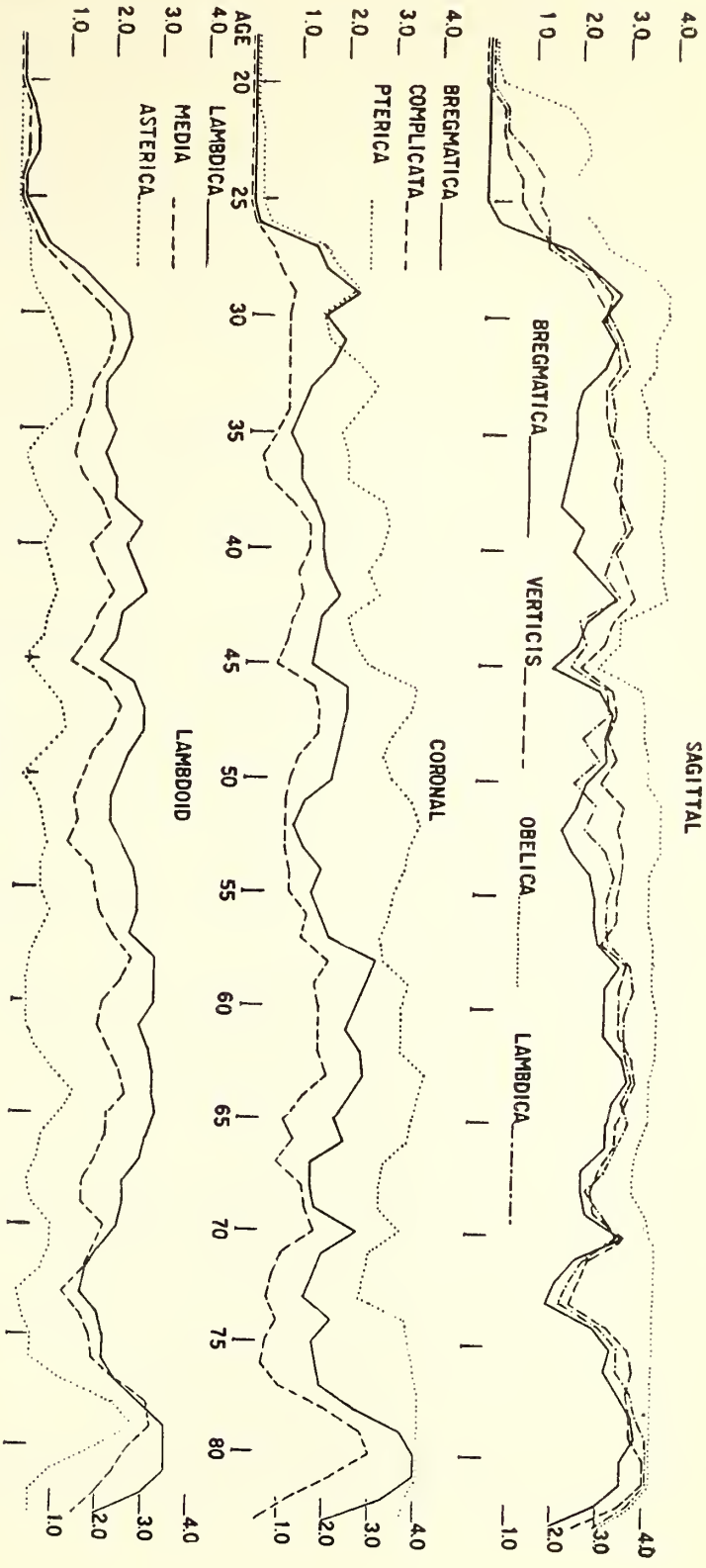

FIG. 1. Ectocranial closure progress in the sutures of the vault. The years between twenty-six and thirty form the period of election for suture closure. The pars obelica of the sagittal has a pattern of its own. Coronal progress slightly precedes lambdoid. The coronal pattern differs somewhat from the endocranial pattern (Fig. 4).

The terminal drop on all our ectocranial graphs is without significance. It results from a meager supply of aged crania and is allowed to remain in the graphs simply to emphasize the plain fact of individual variation.

No reference to right and left sides is made in this work: we find no essential difference in closure pattern and the discussion would have served only to prolong the paper without adding to its value.

Without further preamble we may consider the closure patterns of the several sutures.

I. Sutures of the Vault

THE SAGITTAL SUTURE

Fig. 1.

In spite of the tendency for ectocranial and endocranial closure to commence and continue step by step together, within the limitations outlined above, there is no suture which better displays an attempt at discrepancy. This however affects merely the initial stages of closure. Comparison of ectocranial and endocranial graphs shows a single fundamental pattern for both.

The obelica is a law to itself: the partes verticis and lambdica run together and there is an initial lethargy in the bregmatica. This feature of the bregmatica is not apparent endocranially.

The main points in ectocranial closure are the following.

Closure in the pars obelica commences at twenty years with
- (a) a sharp rise to 2.1 at twenty-three,
- (b) a lethargic period until twenty-six,
- (c) a second period of marked activity terminating at twenty-nine years when closure has reached 3.9 which is of course practical completion.

Closure in the pars lambdica commences at twenty-one years with
- (a) a steady rise to 1.2 at twenty-four followed by
- (b) a pause until twenty-seven when there occurs
- (c) a sharp rise to 2.4 at twenty-nine years and
- (d) merely oscillations thereafter.

Closure in the pars verticis commences also at twenty-one years with
- (a) a gradual and probably retarded rise to 0.7 at twenty-five,
- (b) rapid progress to 2.7 at twenty-nine years and
- (c) merely oscillations thereafter.

Closure in the pars bregmatica commences at twenty-six and
- (a) rises rapidly to 2.9 at twenty-nine years with
- (b) merely oscillations on the graph thereafter.

There are certain features well exemplified by sagittal suture closure which should not be passed over. The partes verticis and lambdica,

though separated by the obelica, run a parallel course and the bregmatica, though catching up later, at first presents a pattern of its own. Hence we must not stress location too hard as an influence in determining closure pattern. The paramount influence is probably a much deeper one, of which location is merely one expression. The period of activity between twenty-six and thirty years is strikingly demonstrated and even more arresting is the evident lethargy or inhibition taking place about the latter age. Endocranially we have seen some evidence of secondary periods of activity succeeding this one and there is slight evidence ectocranially also but it is veiled by the failure of union to progress to completion.

The feature which, above all, one would like to emphasize is the plainly marked effort at closure which makes itself evident in the early twenties. If a suture shows no attempt at closure by twenty-two years it will not start until the period of special sutural activity, namely twenty-six years. This is very important: we shall term the phenomenon spurious effort and shall find it in suture after suture. Stevenson has shown the periodicity in epiphysial union (5) and we know that in the early twenties this activity undergoes a marked decline. Our belief is that certain sutures, being ripe as it were, get caught in the last phase of this activity and make their spurious effort. Further progress in their union is lacking for sutural union, like epiphysial union, becomes lethargic. When the real period of activity in sutural closure commences at twenty-six this dormant energy again is let loose and real progressive union takes place.

Endocranially closure in the sagittal suture commences at twenty-two years but a year earlier in the obelica, and by twenty-four has spread to all parts of the suture. In the obelica union progresses rapidly until its completion at twenty-nine but in the other three parts the progress is slow until the end of the twenty-sixth year when a spurt takes place and brings about practical completion of closure by thirty-one. We may safely disregard the final lethargy. The initial and terminal differences between ectocranial and endocranial union are of no particular significance. On both aspects there is the spurious effort in the early twenties quickly inhibited, and the characteristic rapid progress between twenty-six and thirty years.

THE CORONAL SUTURE

(Fig. 1.)

Ectocranially there is a pronounced difference between successive parts of the coronal suture and a tradition has grown up that so great

a difference in appearance is accompanied by a real difference in date of union. The actual facts about this suture show no such difference.

Closure in the pars bregmatica commences at twenty-six years with
- (a) a sharp rise to 2.3 at twenty nine and
- (b) no further progress but merely oscillations thereafter.

Closure in the pars complicata also begins at twenty-six with
- (a) a well sustained but not sharp rise to 0.9 at twenty-nine and
- (b) no further progress but merely oscillations in the curve thereafter.

Closure in the pars pterica commences at twenty-two years but
- (a) the initial rise which has reached only 0.4 by twenty-six is obviously of a spurious nature, whereas
- (b) real union then sets in with a sharp rise to 2.3 at twenty-nine and
- (c) continues as an oscillatory rise to 3.8 at about fifty years with
- (d) no further real progress.

There is some justification endocranially for the segregation of the pars pterica from the rest of the suture although it is true that the difference is not great, but it is of the order and in the direction which one would expect. Ectocranially one does not find this difference: the early spurious rise need not be taken into account. The influence, whatever it may be, which totally prohibits completion of ectocranial union—resulting in lapsed union as we have termed the phenomenon—is more pronounced in the upper and middle parts of the suture. Whereas endocranially complete union of the pterica has taken place by forty-one years this is delayed ectocranially until fifty. Apart from this fact there is no real difference in closure on the two cranial aspects in any part of the suture.

THE LAMBDOID SUTURE

(Fig. 1.)

On the endocranial aspect we found it advisable to separate the pars asterica from the remainder of the suture. Ectocranially also there is a distinction and by its nature this distinction serves to accentuate the difference already defined. We may nevertheless set down the main features of lambdoid closure together.

Closure in the pars lambdica commences at twenty-one years with
- (a) a spurious rise which rapidly fades from the graph and is replaced by
- (b) the real commencement at twenty-six which rises to 2.3 at thirty and

(c) is followed merely by oscillations.

Closure in the pars media also commences at twenty-one with

(a) a spurious rise which rapidly fades and gives place to

(c) the real commencement at twenty-six which rises to 1.9 at thirty

(c) and is followed by oscillations only.

Closure in the pars asterica commences at twenty-six with

(a) a slow rise to 0.6 at thirty

(b) seeming to be continued to 1.2 at thirty-four but in reality this is nothing more than a swing of the characteristic oscillations.

Lambdoid closure ectocranially occurs then simply between the ages of twenty-six and thirty. The graph shows selective action of the inhibitory influence very well: it is most pronounced in the asterica and least in the lambdica. Ectocranial and endocranial union keep pace with each other in very accurate fashion, allowing for the lapsed union of the ectocranial surface, for in all parts of the suture closure commences at twenty-six and the rapid progress ends at thirty. Further, inhibition seems to have the same relative effect upon the three parts on both aspects.

II. The Circum-Meatal Sutures

In this group of sutures the only one to show any closure activity in the typical period of twenty-six to thirty years is the masto-occipital and it is very slight. The inferior part, which atttains considerable union endocranially before thirty, progresses very little on the outer surface by this age. The spurious start of the parieto-mastoid suture is probably the result of an accidental overflow of the abundant closure energy of the period.

In general, inspection of the graphs shows nothing but a slow, continuous but oscillatory progress. But closer study seems to disclose periods of secondary activity commencing about thirty-seven and sixty years. We happen to know from other researches that there is a significant activity commencing in the skeleton about thirty-seven which results in the formation of rims to the articular surfaces, a feature hitherto confused with pathological lipping. There appears to be no good reason why suture closure may not share in this energy. The cause of the activity about sixty has not yet disclosed itself to us.

The ectocranial features of closure in this group very closely resemble those of endocranial union but owing to a greater effect of the restraining influence all delicate distinctions between the several parts of the

various sutures is lost. Endocranially we were able to demonstrate varying degrees of emancipation from the typical pattern as exemplified by the vault sutures. This emancipation reaches its apogee in the squamous suture and becomes less as one follows the spheno-temporal forward or the parieto-mastoid and masto-occipital backward. Ectocranially however squamous, parieto-mastoid and spheno-temporal all commence to unite about thirty-six to thirty-eight and the masto-occipital between twenty-six and twenty-eight. Having in mind the scheme of emancipation so clearly shown on the endocranial aspect it is not difficult to pick out a similar but much less marked closure pattern on the external aspect.

THE MASTO-OCCIPITAL SUTURE

(Fig. 2.)

On the endocranial aspect the third or inferior part of the masto-occipital suture shows quite clearly a pronounced activity in closure during the typical period of suture closure, that is, between twenty-six and thirty years. Ectocranially this marked rise of the curve is not apparent and consequently there is nothing in this graph to arrest attention: all parts of the suture seem to be closing gradually and with more or less regular progress. No justification exists for separating the inferior part from the other two parts in description. No better instance could be cited of the relatively featureless pattern of closure on the ectocranial aspect when compared with endocranial closure. Had we depended upon ectocranial closure for our fundamental investigation, as so many of our predecessors have been compelled to do, we should have found it difficult if not impossible to unravel the tangled skein of suture closure.

The facts concerning union in the masto-occipital suture are the following.

Closure in the pars superior shows

(a) a spurious commencement at twenty-one years quickly fading and

(b) giving place to the real start at twenty-eight which rises to a peak of 0.8 at thirty-two years and continues as

(c) an oscillatory but certain slow progress attaining a final peak of 3.0 in old age.

Closure in the pars media is essentially the same: there is

(a) a spurious rise at twenty-two followed by

(b) the real commencement at twenty-eight which rises to a peak of 1.0 at thirty-two and gives place thereafter to

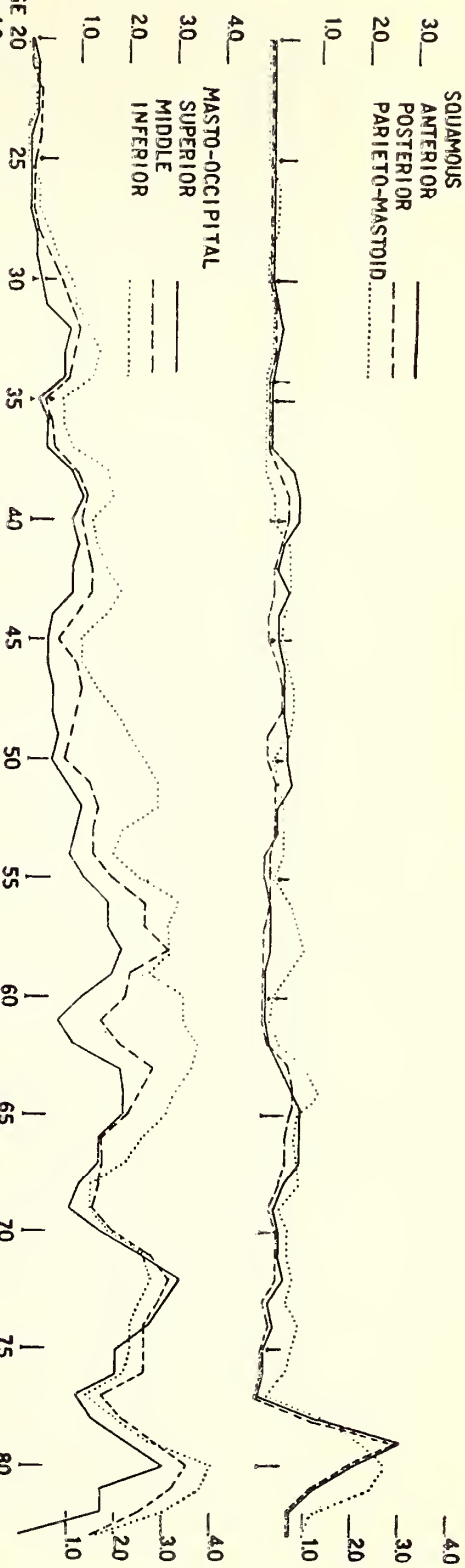

FIG. 2. Ectocranial closure progress in the circum-meatal and accessory sutures. Progress in all these except the spheno-frontal is obviously different from that of the vault sutures. The patterns of the inferior masto-occipital and of the spheno-frontal differ from the corresponding endocranial patterns (Figs. 6, 7). Evidence of subsidiary periods of activity appear in these sutures in the late thirties and about sixty. The final drop is the result of very few aged skulls erratic in their suture closure. Lapsed union is characteristic of all ectocranial sutures.

(c) an oscillatory but nevertheless progressive union reaching a peak of 3.5 in old age.

Closure in the pars inferior presents

(a) the usual spurious rise: it commences at twenty-one years but

(b) the real start is seen at twenty-six and by a rapid rise the curve climbs to 1.4 at thirty-three after which there is

(c) oscillatory progress until a peak of 3.6 is reached at sixty-two with the possibility of complete closure in extreme old age.

Both ectocranially and endocranially the pars inferior commences to unite at twenty six and there is more marked progress endocranially, less marked progress ectocranially, until thirty but the impetus is carried over on both aspects until thirty-three years when an oscillatory appearance of the graph obscures the changes which the suture is undergoing. Endocranially there seems to be some evidence of a rather stationary period terminating in a fresh subsidiary activity at about forty-nine years which continues throughout life thereafter. Ectocranially one cannot distinguish this periodicity.

In the superior and middle parts of the suture closure commences ectocranially at twenty-eight but endocranially not until thirty years. There follows a short period of considerable activity terminating on both cranial aspects at thirty-two, the endocranial aspect showing by then a greater degree of union than the ectocranial. If the periodicity suggested on the endocranial aspect be genuine it is very feeble and does not appear at all on the outer surface of the cranium. There is however on both sides a slow progress maintained throughout the greater part of life.

THE SPHENO-TEMPORAL SUTURE

(Fig. 2.)

Ectocranially there is no advantage in separating the descriptions of the two parts.

Closure in the pars superior shows

(a) a slight and probably spurious commencement at thirty-one years,

(b) the real commencement at thirty-seven with little or no progress

(c) but a secondary spurt in the early sixties with

(d) merely oscillations thereafter.

Closure in the pars inferior also shows

(a) a probably spurious effort at thirty-one years,

(b) the real start at thirty-six, again with little progress but

(c) a secondary period of activity about sixty-five and
(d) oscillations thereafter.

Endocranially there is the same early activity at thirty years which rapidly comes to an end and is probably spurious, the real commencement appearing in both parts at thirty-six. There is little further activity in the pars superior until the spurt occurs in the early sixties but the pars inferior shows no such spurt. In it there is continuous slow progress as on the outer aspect of the cranium, reaching its maximum in the later sixties.

THE SQUAMOUS SUTURE

(Fig. 2.)

On the ectocranial aspect of the cranium as on the endocranial it is unnecessary to separate the anterior from the posterior part of this suture in treatment. The closure curves for both parts and indeed for both aspects run almost parallel. Ectocranially there is an obvious false start in both parts at thirty-one years. These spurious efforts may be disregarded: they are characteristic of all circum-meatal sutures.

Closure in both parts

(a) apart from the spurious effort starting at thirty-one years,
(b) commences at thirty-eight and reaches its peak in one year, namely 0.6 for the anterior part and 0.5 for the posterior. Then follows
(c) a period of oscillation with perhaps
(d) a spurt of secondary activity in the early sixties.

Closure in this suture commences on both sides of the cranium at thirty-seven or thirty-eight and the secondary activity in the early sixties is well marked endocranially. As usual, closure progresses to a much greater degree on the endocranial aspect than on the ectocranial.

THE PARIETO-MASTOID SUTURE

(Fig. 2.)

As on the endocranial surface, closure of the parieto-mastoid suture closely follows union of the squamous. There are two spurious efforts at twenty-six and thirty-one years before the real start. Whether there is simply oscillatory progress or an actual secondary period of activity in the late fifties and early sixties one finds it difficult to decide: the probability is in favor of secondary activity.

Closure starts

(a) after two spurious efforts
(b) at thirty-nine and makes very little progress until there appears

(c) a secondary period of activity in the late fifties and early sixties when a peak of 1.2 is reached at sixty-four and thereafter

(d) merely oscillations.

Endocranially closure starts at thirty-seven and shows the same lethargy until the secondary activity of the fifties.

III. The Accessory Sutures

The two parts of the spheno-frontal suture are not strictly comparable on the two aspects of the cranium and one finds quite a different scheme in the graphs. Endocranially the two parts run a parallel course different from that of the spheno-parietal, but ectocranially the orbital part runs its own course whereas the temporal part and the spheno parietal suture run practically the same course.

One can trace relationship with vault suture pattern in the orbital part alone. The spheno-parietal and the temporal spheno-frontal on the other hand resemble in their graphs the inferior spheno-temporal and in a general way the masto-occipital also in all its parts. One would be very unwise however to inspect these ectocranial graphs alone in the hope of obtaining a mental picture of the suture closure relationships. An indispensible preliminary is the study of our endocranial graphs.

THE SPHENO-PARIETAL SUTURE

(Fig. 2.)

The ectocranial graph for the spheno-parietal suture is an almost exact replica of the endocranial graph but with somewhat less progress year by year.

Closure commences at twenty-eight years

(a) with a slight rise to 0.5 at thirty-one sustained until the

(b) secondary period of activity commencing at thirty-six and reaching 2.0 at thirty-eight but

(c) continuing with diminished and oscillatory vigor until the early sixties.

Endocranially closure begins at twenty-nine and also encounters the delaying influence almost at once. The same spurt in the late thirties is apparent and the continued oscillatory activity. At sixty-five complete closure is attained.

THE SPHENO-FRONTAL SUTURE

(Fig. 2.)

The similarity of the graphs of the two parts, so characteristic of the endocranial surface is not to be found on the ectocranial aspect: nor is there an early start ectocranially.

Closure in the temporal part commences at twenty-eight with
(a) a gradual rise to 0.7 at thirty-one sustained until thirty-five;
(b) then a fairly sharp rise to 2.1 at thirty-eight followed by
(c) a slow oscillatory progress until sixty-five when complete closure may be attained.

Closure in the orbital part commences also at twenty-eight with
(a) a rapid rise to 2.3 at thirty-one sustained until
(b) secondary activity sets in at thirty-six and continues until forty-six when the graph reaches 3.8. This activity is followed by
(c) merely oscillations thereafter.

On the endocranial surface closure in both parts starts at twenty-two, rises to 0.7 at twenty-six and 3.0 by thirty years. After this there is a period of oscillation lasting until sixty-four when complete closure takes place.

The orbital part of the spheno-frontal suture is the only one of the accessory group which at all resembles the pattern of the vault sutures. Its graph recalls those of the lambdica and media of the lambdoid. Endocranially the inferior part of the masto-occipital looks quite like it but there is no resemblance ectocranially. On the other hand the asterica of the lambdoid quite closely resembles in pattern the graphs of the temporal part of the spheno-frontal and of the spheno-parietal. One would easily lose one's way in the maze of ectocranial patterns were it not for the help afforded by the endocranial graphs.

COMPARISON OF STANDARDS

Our work differs fundamentally from that of almost all previous investigators because we seek to establish a definite age relationship in the closure of sutures whereas they, dealing with a number of crania of unknown and quite various age, could base their observations solely upon a general average which they termed a closure tendency. It is apparent that this closure tendency would differ with every collection of crania. Previous workers have been compelled also by circumstances to concentrate the bulk if not the whole of their investigations on the exterior of the cranium: few have had the opportunity of studying any of the endocranial sutures save those of the vault. This being the case it would simply be wearisome and indeed profitless to make comparison with previous results in detail: by their nature they could have merely a temporary value and may now be considered obsolete.

Regarding certain of the major conclusions we should however say a few words. It has been asserted that ectocranial closure is a very

different thing from endocranial union, that it commences in a different part of the suture, progresses in a different order and at a different speed. We have shown that, apart from the inferior masto-occipital, the spheno-frontal and in certain respects the coronal, the pattern of the closure graph differs in no essential on the two cranial surfaces. Why these differences should be present in the sutures mentioned we are not yet in a position to explain. As regards precise site of commencement in the several parts of any suture we consider too detailed an insistence as merely a meticulous pedantry: closure commences in the substance of the bone and naturally appears on the surface at rather irregular points and this detail is without significance. We have also shown that lapsed union, so characteristic endocranially in the pars lambdica of the lambdoid suture but by no means uncommon in the sagittal suture, is also characteristic of all the ectocranial sutures and to a much greater degree. Why this should be so we are not yet able to explain. There is no doubt, as our graphs demonstrate, that this lapsed union is the feature which has misled previous workers and brought about the belief that suture closure tends to occur earlier on the endocranial aspect. It is indeed somewhat surprising that the spurious efforts at closure so obvious in our ectocranial graphs, resulting from a precocious attempt at union in certain crania, has not drawn previous workers into the erroneous assertion that closure tends to take place earlier on the exterior of the cranium. The relative order of closure and the date at which each suture commences to unite, as given by former investigators, we would simply turn out of court as unsatisfactory and frequently prejudiced evidence. If the reader will take the trouble to read again at this juncture the historical introduction to our first paper (6 pp. 326–330) he will appreciate better the value to be placed on each of the main investigations previously published upon the subject. We are content to rest our case and will occupy no more space with a discussion which we regard as unnecessary.

THE SKULL OF DESCARTES

In our former paper we have drawn attention to the difference between the significance of this work for modal closure order and dates of a population on the one hand, and for the determination of age in individuals on the other. We have claimed, and we persist in our claim, that while there are individual differences of frequent occurrence in order and date, sometimes even of considerable magnitude, our final published graphs do give the modal order and dates for the population at large. We have already shown by a special investigation how far our

conclusions may be depended upon for discussion of an individual skull (6 pp. 379–380). Instead then of continuing this theme in the present paper we propose to discuss a single well known skull, namely that claimed to have belonged to the famous philosopher Descartes.

The authenticity of this cranium has been repeatedly called in question, first by Lenoir in his letter to Cuvier, most recently by the Académie des Sciences in 1912. Verneau (9) gives a brief history of the wanderings of the skull up to the time when it was sent by Berzélius to Cuvier in 1821 by the hand of the Swedish ambassador in Paris. Both Verneau and Richer (4) conclude that the skull is authentic by comparison with the portrait by Franz Hals. This indeed was the basis upon which Cuvier inclined to accept the skull as genuine. It is true that comparison with other portraits has not such a happy result but Miss Tyldesley has shown in her excellent study of the skull and portraits of Sir Thomas Browne that portraits have often been copies one of another and that the artistic convention of the day has brought about alterations in proportions so great that the original resemblance may be and often is entirely lost (8). So far as this method of study permits comparison there seems no good reason to doubt that the skull is indeed that of Descartes.

Ribbe in 1885 (4) took pains to examine the skull carefully and notes that although Descartes was fifty-four years old at the date of his death union of sutures had not yet begun. Presumably this refers to the exterior of the cranium. Comparing the cranium with those of other distinguished men in the Gall collection Ribbe concludes that intellectual men as a rule possess sutures which unite comparatively late in life. I am not in a position to discuss this point but, upon the basis of the results of our study of male white suture closure on both surfaces of the cranium, it is clear that the balance of evidence seems at first to be against the cranium being that of a man of over fifty years. Nevertheless the matter is worthy of further study. The texture of the cranium would yield very valuable information, for the bone in a skull of fifty years differs quite markedly from that of a skull of the third decade to which it ought normally to belong when the sutures show no sign of closure.

I have therefore reviewed our collection to see if I could match the condition found in the presumed cranium of Descartes and I find an apt comparison in No. 758, a White male, native of Austria, who died from a fractured skull at the age of fifty years. This cranium is mentioned in our earlier article (6 p. 360). It shows no endocranial union except in the pars complicata of the right coronal suture. Ectocranially

there is no union whatever. The capacity of this cranium is 1555 cc and it belongs to the δ group: that indicates a well filled cranium of a high type as will be shown in a forth-coming paper. The subject has already been discussed in a preliminary manner (7,pp. 250–252). The cranium is characteristically thin but it shows a peculiar texture associated in my experience with liability to fracture. I do not believe that size, texture or thinness is related to the lethargy in suture union: we have indeed the skull of an old Negress of seventy years (No. 152) in which also there is scarcely any trace of suture closure.

The author who, up to the present, has had the greatest experience of suture closure in skulls of known age is de Aranzadi who had at his disposal 1212 skulls, mostly of known individuals (1). This writer realized the magnitude of individual variability in date of suture closure and was forced to the conclusion that the cranium offers no certain sign (in suture closure of course) of the precise age of the individual to which it belonged. With this conclusion we quite agree although we insist that individual variability must not be allowed to obscure the fact that there is a modal progress which holds for the population in general.

So far as Descartes is concerned we would not seek to maintain that the unclosed condition of the sutures constitutes an insuperable bar to the presumption of authenticity for the cranium ascribed to this distinguished man, but we do not believe that his intellectual condition was necessarily associated with the lethargy of union, and we would emphasize strongly that the texture of the bone might well give surer evidence of the decade in which his death occurred.

Having mentioned Sir Thomas Browne we cannot but record our regret that sutures of this thoroughly authenticated cranium do not seem to have received adequate study before re-inhumation. Examination of the published figures yields only presumptive evidence that the sutures on the exterior also exhibit lack of union in spite of the fact that Sir Thomas was seventy-seven years old at the time of his death. This is in marked contrast to the suture condition of Immanuel Kant (2, pp. 373–375). If our interpretation of the cranium of Browne be correct we have one more example of the extent of individual variability. The published photographs show the texture of Browne's cranium to be that of a very old man.

SUMMARY

This paper is a continuation of the work upon suture closure and deals with ectocranial union in White males. We have presented evidence which we believe justifies the following conclusions.

1. Suture closure in general makes itself evident upon both ectocranial and endocranial aspects of the skull at one and the same date. The belief that endocranial closure precedes ectocranial union is without real foundation. To this there are exceptions where union may appear on one aspect a year or two before it is obvious on the other. Such differences are without significance. The pterica of the coronal suture is a case in point.

2. Ectocranial closure progresses more slowly and shows more individual variation than endocranial closure. It is therefore not so reliable as an age indicator.

3. Lapsed union so characteristic of parts of the lambdoid and sagittal endocranial sutures is equally characteristic of all ectocranial sutures. In consequence ectocranial sutures tend to remain in a state of incomplete union, some in very high degree.

4. The years twenty-six to thirty form the period of election for both ectocranial closure and endocranial closure. During this time most of the union which is going to occur takes place. There are however secondary periods of ectocranial activity, namely during the later thirties and about sixty years. These compare well with the evidence of the endocranial sutures. Ectocranially the third subsidiary period in extreme old age, namely in the late seventies, does not appear.

5. The closure patterns on the ectocranial surface are practically the same as those of the endocranial aspect except in the coronal, spheno-frontal and inferior part of the masto-occipital sutures. Why differences should occur in these sutures we are not yet able to explain.

6. Although closure occurs in coronal and lambdoid mainly during the period of election, namely between twenty-six and thirty years, ectocranially as well as endocranially, the coronal has a slight lead in the progress of closure.

7. Precise dates for suture closure and the order of progress are to be found in the text. It is unnecessary to repeat them here but there is no essential change from the endocranial patterns except in the sutures mentioned in paragraph 5.

8. The three types of suture, namely vault, circum-meatal and accessory, are apparent ectocranially but their segregation would not be very clear were it not fully demonstrated on the endocranial aspect.

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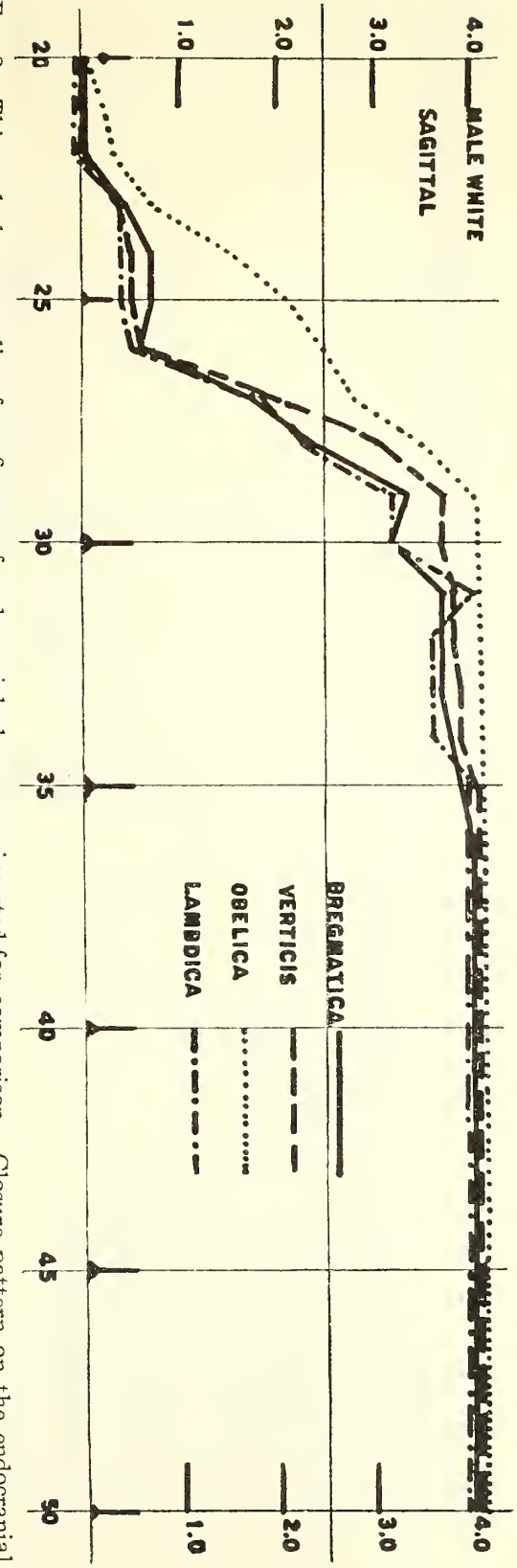

FIG. 3. This and the succeeding four figures of endocranial closure are inserted for comparison. Closure pattern on the endocranial aspect of the sagittal suture. Note the obelica.

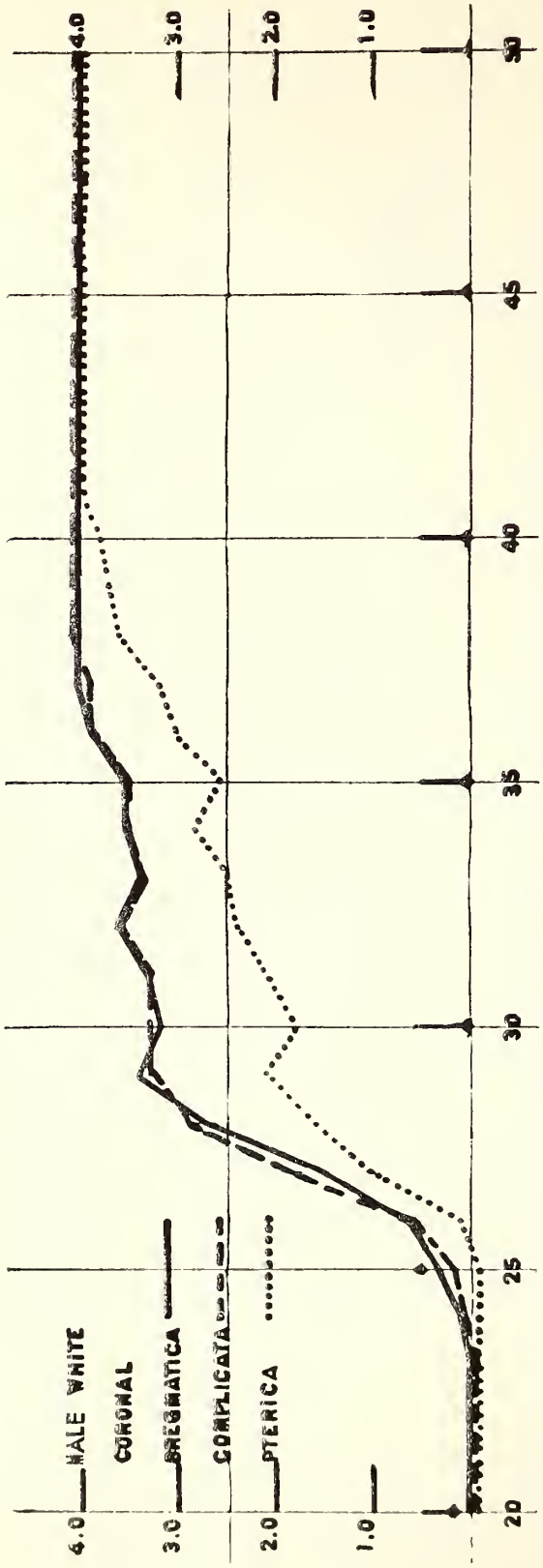

FIG. 4. Endocranial closure progress in the coronal suture.

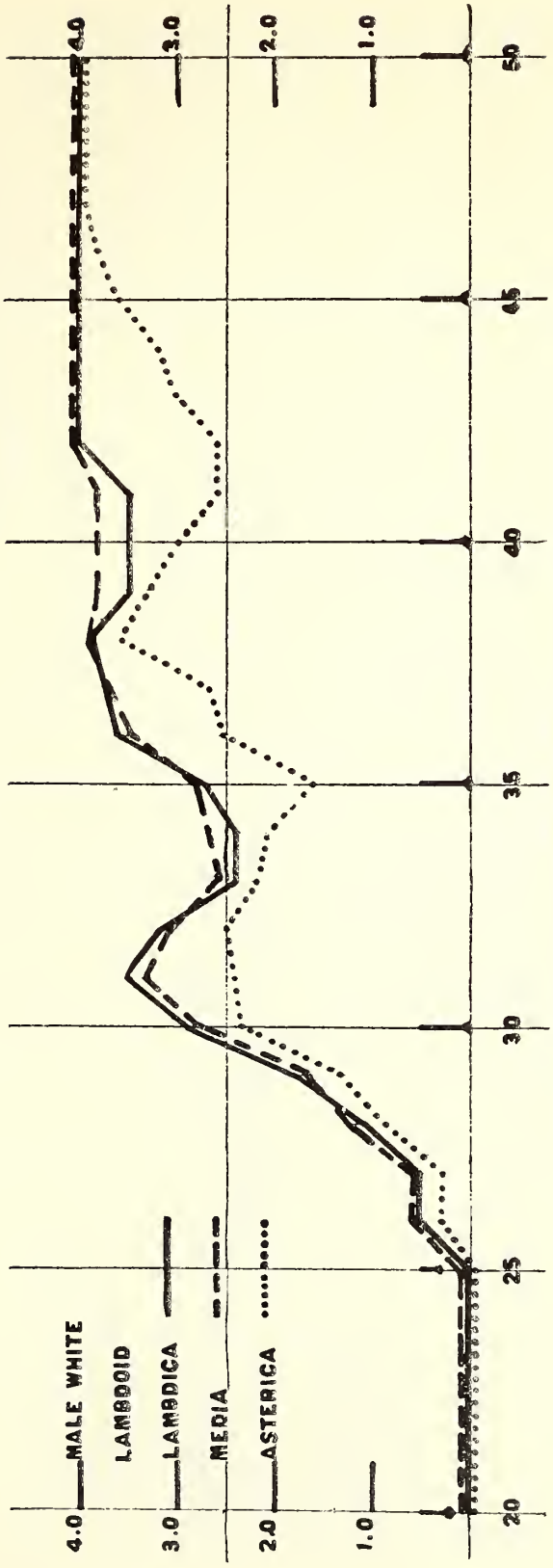

FIG. 5. Endocranial closure progress in the lambdoid suture.

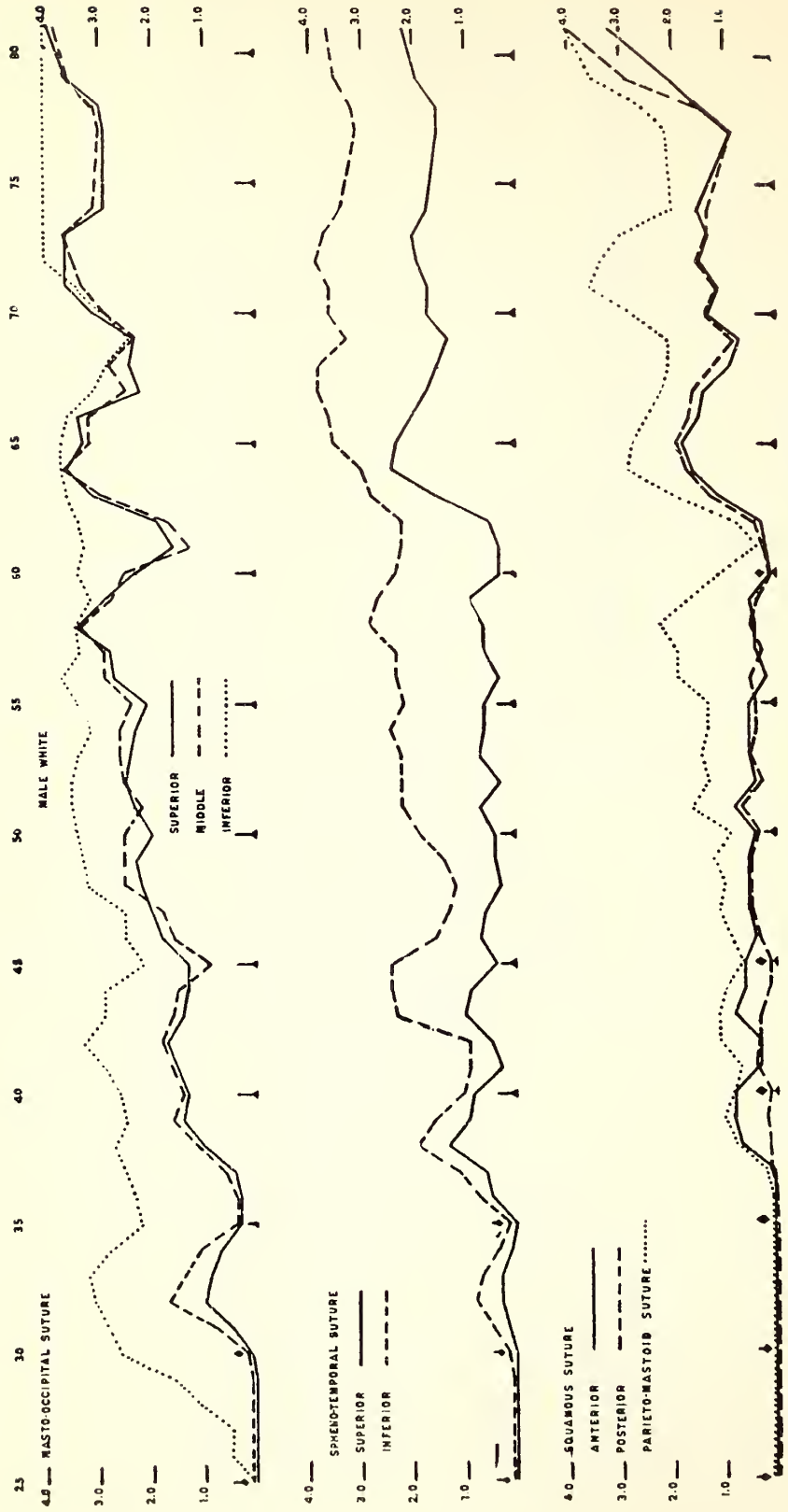

FIG. 6. Endocranial closure progress in the circum-meatal sutures.

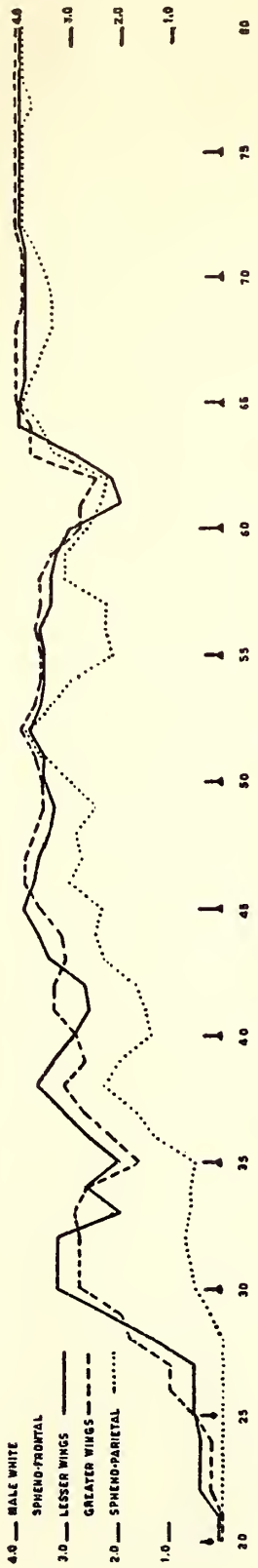

FIG. 7. Endocranial closure progress in the accessory sutures.

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